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RETURN IRRIGATION WATER. CHARACTERISTICS AND EFFECTS

Edward F. Eldridge

Public Health Service
Portland, Oregon

1 May 1960

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RETURN IRRIGATION WATER

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CHARACTERISTICS AND EFFECTS

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DIRECTOR

RESEARCH AND TECHNICAL CONSULTATION PROJECT

U.S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE

PUBLIC HEALTH SERVICE

REGION IX

PORTLAND, OREGON

May 1, 1960

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RETURN IRRIGATION WATER -
CHARACTERISTICS AND EFFECTS

FOREWORD

This paper will show and document, by means of references to published material, that return irrigation water is a major factor affecting the quality of surface and ground waters in a considerable portion of this country. In considering this effect and its magnitude, it is necessary to have up-to-date knowledge regarding the acreage of land under irrigation, the quantity and quality of the water required for irrigation, the disposition and use of this water, the factors influencing the quantity and quality of the water returned to surface or ground supplies, and the effects of this return flow on further use of the supplies in a complex of multiple uses.

This investigation has shown that the potential water quality problems involve changes in salinity and hardness, temperature, turbidity, nutrients and aquatic growths, odor and taste, nitrates, and sanitary quality. Each of these factors is developed and documented and the actual and potential effects on water uses are analyzed. The major water uses considered are domestic and industrial water supply, fisheries, recreation and irrigation.

A considerable mass of field data pertinent to the problem of the quality of return irrigation water has been collected. Very little of this information relates to the effects of the quality of the return irrigation water on water uses other than irrigation. However, these data are useful in an interpretation of these effects. As would be expected, there are voids in the information.

DEFINITIONS

Since most of the data and information contained in this report was taken from agricultural literature, some of the terms used have a meaning which differs from that used in other fields. The following terms are defined to avoid misunderstanding.

Irrigation water	Water diverted from a surface or ground water source for the purpose of irrigating land.
Return irrigation water	Water which returns to a surface or ground water as a result of irrigation practices.
Salts	Dissolved mineral matter including mineral salts.
Salinity	Concentration of dissolved mineral salts.
Salt balance	The quantity of salts entering an area by way of the irrigation water as compared with the quantity of salts removed from the area by return water.
Consumptive use	The water lost by evaporation and transpiration.

SUMMARY

Insofar as possible, using existing data, the various problems related to the quality of return irrigation waters and its effect on water uses have been discussed and documented in this report. Documentation was accomplished by reference to specific examples. Where additional information is needed, this is so stated. The following is a summary of the results of this study:

1. Return irrigation water is a major factor affecting the quality of surface and ground waters of large sections of this country. Some of these effects are apparent or can be inferred from the results of studies and experience with the use of waters containing these return flows. Other effects are only indicated and their magnitude and significance is not entirely in evidence.

2. There is a distinct difference between irrigation in the arid western states and supplemental irrigation in the humid areas of the East so far as the return flow problem is concerned. Although there is a lack of data concerning return irrigation flows in humid areas, the evidence available indicates that supplemental irrigation will not significantly affect water quality in these areas. This report, therefore, deals with the situation as it exists in the arid areas west of the Mississippi River and only brief mention is made of irrigation in humid areas.

3. The magnitude of the return flow problem is indicated by the quantity of water involved in the irrigation of land. In 1956, over 36,000,000 acres were under irrigation in this country of which 91 percent was located in 17 western states. Some authorities feel that by 1970 most of the potential area in these 17 states, over 51,500,000 acres will be irrigated. However, the increasing cost of facilities and lack of water will undoubtedly retard the rate at which the remaining acreage is developed.

4. About 128,000,000 acre feet or almost 41 trillion gallons of water are used annually for irrigation.

5. An average of about one-third or 14 trillion gallons of this water is returned to surface or ground water sources as return irrigation water. The quantity of water returned varies from 20 to 60 per cent of the water diverted for irrigation. The remainder is lost by evaporation and transpiration.

6. Return flows may be made up of three components; namely, overflow, runoff, and seepage (drainage). These are present in varying proportions in the return water.

7. Successful irrigation requires that a "salt balance" be maintained in the soil which means that the salt (dissolved mineral matter) output by-way-of the return flow must equal or exceed the input by-way-of the irrigation water. Since this salt is contained in a much smaller quantity of water, the concentration in return flows is always greater than that of the irrigation water unless there is storage of salts in the soils. High salt concentration will eventually damage the soil for cropping and is avoided when at all possible.

8. Examples are discussed in the Appendices of this report from which it appears that salt concentrations in return flows are from 5 to 10 times greater than that of the irrigation water.

9. Mineral concentration is one of the major quality factors affecting the use of water containing return irrigation flows, and it is desirable to be able to roughly estimate the expected concentration of salts in return flows from new projects. The various factors influencing this concentration are discussed in the report and a suggested method and formulae by which such an estimate can be made are developed.

10. Not only is there an increase in salt concentration, but there is also a shift in the proportion of the various cations and anions which make up these salts.

11. Most ions increase, but the percentage increase of each differs. Of the cations, the percentage increase in calcium is lowest, while sodium is usually the greatest. In some cases, however, magnesium showed a greater increase than sodium, probably due to its presence in the rock formations of the area. The anion, bicarbonate, increases but slightly and in some cases diminishes. Both sulfate and chloride increase greatly with one or the other leading in specific areas.

12. Hardness as calcium and magnesium is from 400 to 700 per cent greater in return flows than in the irrigation supply. In most cases the major increase is in the permanent or non-carbonate hardness.

13. From the standpoint of the use of the water containing return flows, the increase in hardness is perhaps the most significant. This involves problems of water treatment which are both complex and costly in order to make the water usable. In fact, some waters are rendered economically useless due to this hardness and salinity problem.

14. Temperature is one quality of return irrigation water concerning which evidence is incomplete. However, there are indications that irrigation causes substantial increases in the temperature of water receiving return flows. High water temperatures emphasize tastes and odors, increase the quantity of water needed for cooling, cause more

rapid growth of aquatic weeds, increase the rate of decomposition of organic substances, interfere with the propagation and development of some types of aquatic life and activate columnaris disease in certain types of fish. Evidence is presented which indicates that water temperatures in the Yakima River increased 10° to 20°F as a result of irrigation.

15. Turbidity is a quality of return flows which can be largely controlled by preventing runoff and erosion of soil. Turbidities of from 200 to 1000 have been observed in return flow drains and canals. This factor is a definite problem in some areas, but in most cases there is a lack of data on which to evaluate it.

16. There is a limited amount of data available which indicates that return flows may contain compounds which cause color in water supplies. The problem is undoubtedly more significant in some areas than in others.

17. In the over-all analysis neither color or turbidity appear to be outstanding qualities of return irrigation flows. It is desirable however, that tests for turbidity and color be included in future studies of this problem.

18. A quality of return flows which appears to have considerable significance is involved with nutrient concentrations, especially nitrogen and phosphorous. Profuse growths of algae in ditches receiving return water indicate the presence of these key elements, however, data as to actual concentrations are rather meager.

19. Some data are available which show high nitrate concentrations in seepage water from irrigated land. However, the concentration is decreased rapidly due to plant growth in the ditches, consequently nitrates in surface waters receiving the return flow are usually low.

20. Almost no direct information is available regarding the phosphate content of return flows. Increasing difficulties with slime and algae, together with increased phosphate content in streams below irrigation projects, point to the need for further study of this phase of the return flow problem.

21. A phase of the nitrate problem involves the high concentrations found in some ground water supplies. Nitrogen compounds, both organic and inorganic, are converted to nitrates by soil bacteria. Since nitrates are very soluble, they will be contained in the soil water and that portion which escapes the root zone of plants will be removed by the drainage water. If this drainage water reaches the ground water, the nitrates may tend to accumulate since there are no plants to utilize them. Of course, this situation is not limited to

irrigated land and the relative contribution of return flows to the ground water nitrate problem is yet to be determined. Nitrates in water supplies cause methemoglobinemia in infants, if the concentration exceeds about 10 ppm as nitrogen.

22. The contribution of return irrigation water to the taste and odor problems of water supplies is substantiated by experience of water works operators and by studies made in the Rio Grande area. Tastes and odors are the result of the growth of organisms and their subsequent decomposition. One investigator has indicated that the chief contributors are organisms known as actinomycetes, which grow on or in living algae and plants. He indicates that phosphorous is the limiting factor in the growth of these organisms.

23. High concentration of mineral salts, especially chlorides and sulfates, may also be a source of taste problems in water supplies containing return flows.

24. Recent years have seen the development of numerous chemicals for insect sprays, weed control, and other agricultural purposes. Return irrigation flows may be a medium by which these chemicals can enter both surface and ground waters. However, there is a difference of opinion of investigators in this regard, although in no case has any direct evidence been presented to support these opinions. Most of these chemicals are extremely toxic to fish and present a potential hazard to humans worthy of further investigation.

25. The sanitary quality of return irrigation flows is influenced by the condition of the irrigation water applied and by the degree of contamination in the irrigated area. The bacterial content of the applied irrigation water is substantially reduced by its use for irrigation. Bacteria are almost completely removed by passage through from 4 to 7 feet of soil.

26. There is evidence of the contamination of both surface and ground water by direct runoff of irrigation water. In some cases this runoff is directed into underground aquifers which has resulted in the contamination of well water supplies. Experiments with the recharge of aquifers by diluted sewage has indicated that the travel of bacteria beyond 100 feet is negligible unless in a fissured area or gravel strata.

27. Return irrigation flows may carry bacterial contamination into surface and ground waters depending upon local conditions. However, this contamination is not a direct result of irrigation except in those cases where runoff of irrigation water may flush contaminated material from the land into these waters.

PART I

IRRIGATED AGRICULTURE

I. MAGNITUDE OF IRRIGATED AREAS

Present

Irrigation is a major use of water in many parts of this country, especially in the arid and semi-arid regions of the West (1). However, supplemental irrigation is expanding rapidly in the humid Eastern States, thereby increasing this water use in those areas. The magnitude of this water-use problem is governed by the location of the irrigated areas, as well as the acreage under irrigation.

It is estimated that there are almost 250,000,000 acres of land under irrigation in the world today (2). India and China lead with approximately 70,000,000 acres each. The United States is third.

Table I contains data regarding the magnitude and distribution of irrigation in this country (3). The total area under irrigation in the United States in 1956 was 36,002,627 acres. Of this area 32,661,501 acres were located in 17 Western States and 3,341,126 acres in all other states. Table I also shows, in order, the 20 states having the greatest irrigated acreage.

Future

A 17 per cent increase in irrigated acreage in the U. S. occurred during the two-year period (1954 to 1956) covered by the data in Table I. Almost 5,500,000 acres were added during this period. Most of this increase (4,568,554) acres) was in the 17 Western States. Although the acreage in all other states only increased 722,620 acres, the percentage increase was 28 per cent.

About 41 per cent of the land under irrigation is contained in two states, Texas and California. The largest increase in irrigated acreage during the 1954 to 1956 period occurred in Texas (over 1,500,000 acres). Six states increased more than 100 per cent in area irrigated during this period (see Table I). The greatest percentage increase was in Iowa, from 2,396 to an estimated 20,000 acres or 818 per cent.

The rise in irrigated agriculture since 1890 is shown in Figure 1. This curve shows a sharp rise since 1930 and there is

TABLE I

U. S. IRRIGATED ACREAGE*

	Acreage 1956	Acreage 1954	Increase %	Sprinkler**
U. S. Total	36,002,627	30,711,453	17	3,064,463
17 Western States	32,661,501	28,092,947	16	2,010,062
Other States	3,341,126	2,618,506	28	1,054,401
1. California	7,750,000	7,048,792	10	400,000
2. Texas	6,962,234	5,439,000	28	575,015
3. Idaho	2,405,089	2,324,571	3	130,000
4. Colorado	2,382,000	2,263,000	5	33,110
5. Nebraska	2,012,320	1,393,733	44	201,230
6. Montana	1,890,000	1,890,000	--	28,000
7. Utah	1,612,108	1,072,682	50	3,325
8. Oregon	1,575,000	1,490,397	6	157,500
9. Wyoming	1,300,000	1,262,632	3	8,000
10. Arizona	1,150,000	1,250,000	-9	1,000
11. Washington	947,000	778,135	22	228,000
12. Arkansas	892,936	857,390	4	54,756
13. Florida	821,282	428,282	92	180,000
14. New Mexico	800,000	649,615	23	3,000
15. Kansas	722,575	420,000	72	100,000
16. Louisiana	711,000	707,818	1	39,650
17. Nevada	700,000	567,498	23	12,000
18. Oklahoma	285,175	107,981	164	100,882
19. Mississippi	157,000	132,490	19	54,000
20. South Dakota	120,000	90,371	33	20,000
Increase of over 100% in:				
Iowa	20,000	2,396	818	20,000
Maine	6,900	1,097	529	6,850
Georgia	80,000	27,701	189	79,200
Oklahoma			164	
Virginia	45,500	21,805	116	45,050
Delaware	11,000	5,553	100	11,000

*Taken from the 1957 Directory and Buyers Guide. (3)

**31.5% of irrigation in "other states" use sprinkler while only 6.1% of area in 17 western states are sprinkled.

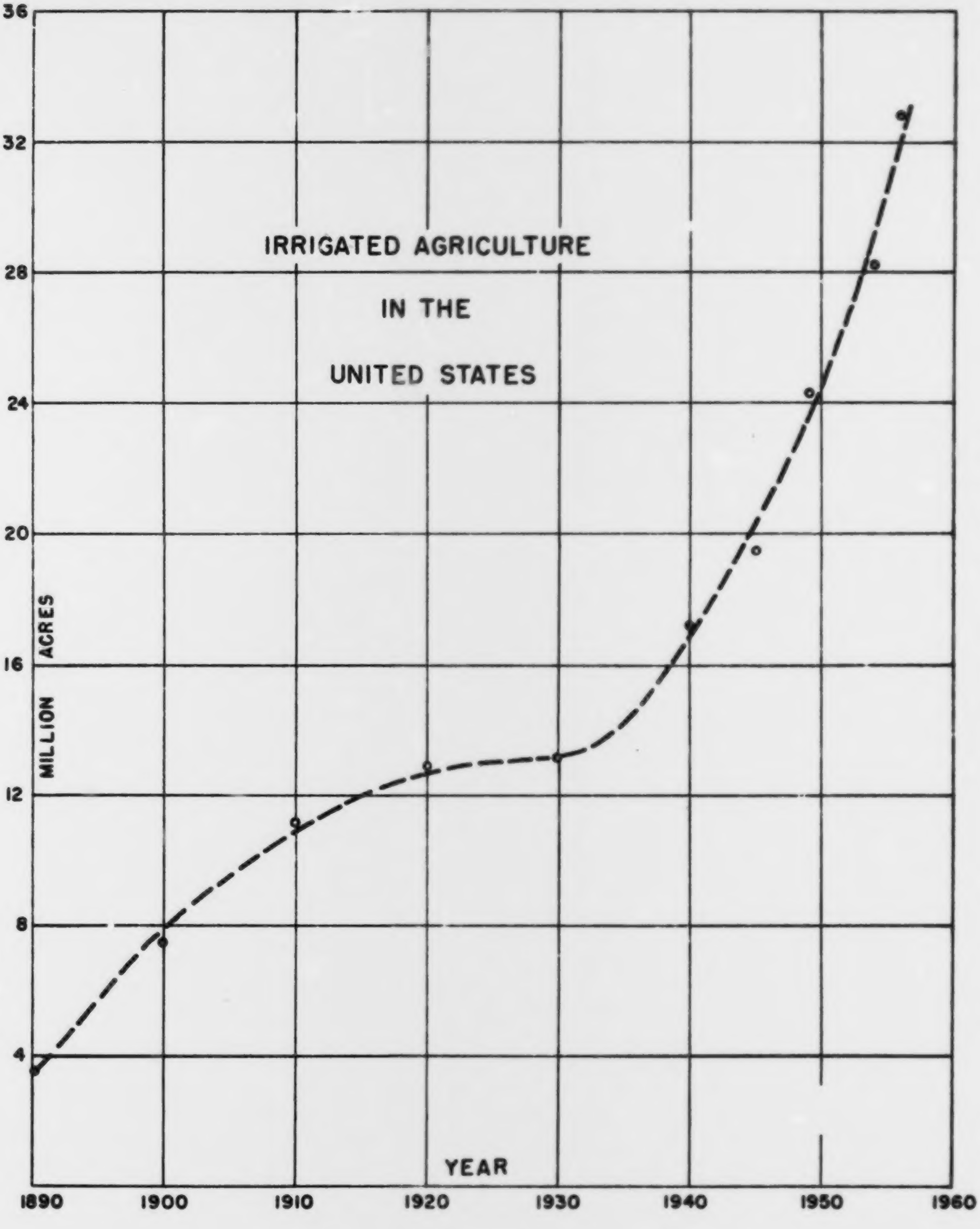

IRRIGATED AGRICULTURE
IN THE
UNITED STATES
MILLION ACRES
36
32
28
24
20
16
12
8
4
YEAR
1890
1900
1910
1920
1930
1940
1950
1960

FIGURE 1

every indication that this rise will continue (4). Irrigation, according to Flaigg (2), "constitutes one of the major solutions to this country's need for food," hence it can be expected that most of the potential acreage in this country will be developed in the not too distant future.

The National Resources Board estimates that the ultimate irrigable area in the 17 western states is 51,534,900 acres. During the ten years between 1946 and 1956 the acreage under irrigation has increased at the average rate of about 1.8 million acres per year. At this rate the ultimate will be reached by 1966 or 1967. However, due to increasing cost of irrigation facilities and the competition for water by other water uses, the rate at which land is placed under irrigation may not be a as rapid as the ultimate acreage is approached. A major portion of the irrigable land in the west may be under irrigation by 1970. According to Ackerman (5), on the basis of economic considerations irrigation "comes out badly in most comparisons" with other water uses. Ackerman gives irrigation but an additional 15 million acres west of the 98th meridian on the basis of available water.

The situation in the eastern humid states is much different. The estimate of potentially irrigable land in the east is 125,000,000 acres. Only a small portion of this land is presently irrigated, although supplemental irrigation is increasing rapidly in many areas. The acreage which will eventually be irrigated in the eastern states will depend largely on the availability of water.

II. ECONOMIC VALUE

Economic considerations pertinent to this project are contained in the following tabulation, Table II, which was taken from the 1950 U. S. Census of Agriculture, U. S. Department of Agriculture for the year 1949 and projected to 1956 on the basis of increased acreage. It is recognized that the 1956 estimate of investment is subject to considerable error due to a difference in unit costs, since the estimate was not corrected by reference to the cost index. These data deal largely with irrigation on arid lands.

The investment in irrigation facilities in this country is an estimated $2,530,000. The cost of the water for irrigation purposes in the western states is about $180,000,000 per year. Although this represents a substantial annual investment in water on an acre-foot basis, the average of $1.58 is low when compared with the cost of water for many other purposes.

The future place of western irrigated agriculture in the economic development of the water resources of the Nation is not entirely

TABLE II

IRRIGATION WATER - QUANTITY AND COST

	1949	1956
United States		
Land under irrigation, acres	25,787,455	36,002,627
Capital investment	$1,886,500,000	$2,530,000,000
17 Western States		
Land under irrigation, acres	24,270,566	32,661,501
Capital investment	$1,832,500,000	$2,460,000,000
Water, total, acre-feet	95,441,000	128,000,000
Water, surface " "	72,226,000	
Water, ground " "	23,215,000	
Cost of water, total	$133,598,000	$180,000,000
Cost per acre	$5.38	
Cost per acre-foot	$1.58	
Rate of application-ac.-ft. ac.	3.4	
Low rate (Rio Grande)" "	2.2	
High rate (Idaho) " "	6.1	
Reservoirs, number	7,393	
capacity, ac-ft.	42,332,466	
Canals, ditches & pipeline, miles	159,400	
All Other States		
Land under irrigation, acres	1,516,889	
Capital investment	$54,000,000	$119,000,000

clear at this time. As the demand for water increases this cost, there will undoubtedly be a shift to uses other than agriculture (5).

III. SUPPLEMENTAL IRRIGATION

Supplemental irrigation is practiced in the humid areas of the East largely to improve the production rather than to provide for new kinds of agriculture. In 1956 over 3,341,000 acres were under supplemental irrigation in the 31 Eastern States. About 32 per cent of this land was irrigated by sprinkler systems. Flooding is used for rice fields mostly in Louisiana and Arkansas. Furrow application is practiced in the citrus fields of Florida. About two-thirds of the acreage irrigated in the East is located in the above three states. The potential for supplemental irrigation is governed largely by the economic advantage resulting from increased production as compared with the capital investment and operation costs. The quantity of water required is small when compared with that needed in arid areas, but may be a limiting factor in some areas.

Little, if any, information is available regarding the quality or quantity of return flows from supplemental irrigation. Problems of quality experience in the arid Western States are not likely to exist under supplemental irrigation, or, if they do, their magnitude will be comparatively small. Most of the quality problems in arid regions are due to evaporation and transpiration and to the presence of soluble salts in the soils under irrigation. Low application rates, low evaporation and transpiration rates, lack of high concentrations of soluble salts in soils preclude major problems from return irrigation flows. The principal effect of supplemental irrigation on other water uses will be related to the quantity rather than quality.

PART II

IRRIGATION WATER

I. QUANTITY CONSIDERATIONS

Over-all Quantities Involved

The quantity of water used for irrigation can be expressed by one of four methods (6): First, by consumptive use, which is the amount of water lost by evaporation and transpiration from a cropped area; second, by the amount delivered to the farms, which includes the seepage and evaporation from distribution ditches or sprinkler system in addition to the consumptive use; third, by the entire water diverted from the streams or pumped from the ground, which is the sum of the amount of water delivered to the farms, the canal losses by evaporation, transpiration and seepage, and the overflow back to the stream; and fourth, by the over-all supply for irrigation and includes evaporation from reservoirs as well as the water diverted or pumped to the irrigation project. The latter is the one most commonly used.

The 1949 Census of Agriculture estimates that 95,441,000 acre-feet of water (over 31 trillion gallons) were used for irrigation during that year. Of this amount about 75 per cent was taken from surface sources and 25 per cent from ground supplies. Projecting this to 1956 on the basis of acreage irrigated, the amount of water used for that year was about 128,000,000 acre feet or almost 42 trillion gallons. (Assuming that this quantity is used over an irrigation season of 128 days at the rate of 1,000,000 acre feet per day, the flow required to supply this quantity would be 490,000 cfs which is approximately equal to two Columbia Rivers at average flow and about five at low flow).

This demand for water presently exceeds any of the other water uses except power. The Geological Survey (6) has estimated the amount of water withdrawn from surface and ground sources in 1950 for rural, municipal, industrial, irrigation and water power purposes. The following tabulation indicates the percentage of the total for each of the uses (omitting hydro-electric power).

Use	Ground	Surface	Total
Rural	8.8	0.5	1.9
Municipal	11.1	6.7	7.5
Industrial	17.1	47.5	42.1
Irrigation	63.0	45.3	48.5
Total	100.0	100.0	100.0

(The above estimates include brackish water used for industrial purposes, which makes the industrial percentage higher than it should be if based on fresh water alone. However, it is not possible to separate fresh from salt water uses in areas where tidal waters are used for industrial supply).

Engineering and Public Works, Library of Congress (7) projects 1900 and 1955 water-use data to the year 1975 (Table III). An increase of 37 per cent in water used for irrigation during the period from 1955 to 1975 is indicated. It is expected that by that time much of the irrigable land, especially in the West, will have been developed. This projection indicates that industrial uses will exceed irrigation use by that date.

TABLE III

WATER USE IN THE UNITED STATES

	1900					
Use	mgd	%	mgd	%	mgd	%
Rural & municipal	5,000	12	22,000	8	37,000	9
Industrial & commercial	15,000	38	120,000	46	246,000	54
Irrigation*	20,000	50	120,000	46	170,000	37
Totals	40,000		262,000		453,000	

*The above estimates are based on the assumption that irrigation use occurs every day in the year. Actually, the season of maximum use is not much greater than four months. This represents a much greater variation than occurs in other uses, although there are seasonal variations in every case.

Methods of Application

There are four methods of application of irrigation water; namely, flooding, furrow, sub-irrigation and sprinkler. Flooding is used where soil salinity is a problem and is best applied to pastures, alfalfa and orchards. Furrow application is used with crops that are planted in rows. Sub-irrigation requires a system of subsurface tiles, but is not used where there is a problem of salinity.

Progress in the development of equipment for sprinkler irrigation has resulted in a substantial increase in this method of application. Table I shows the acreage irrigated by sprinklers (over 3,000,000 acres). About 8.5 per cent of all irrigation in 1956 was by sprinkler systems. It appears thatthe increased use of this type of application will have a significant effect on conserving the quantity of water used for irrigation.

Rates of Application

The Census of Agriculture estimated the average rate of application of water to land in the 17 Western States during 1949 was 3.4 acre feet per acre. The rates ranged from a low of 2.2 acre feet in the Rio Grande Valley to 6.1 acre feet in Idaho. Rates as high as 10 and 12 acre feet have been used in isolated instances. Rates of application in humid areas are usually much lower than those in the arid West and vary from 6 to 15 inches per year (0.5 to 1.25 acre feet).

Application rates are governed by a number of factors such as: the availability and cost of water; local and climatic conditions; methods of application; crops; soil types; and the quality of water used. There is also a considerable difference of opinion among farmers regarding the amount of water required. Excessive use is common in areas where water is available at low cost. This practice results in erosion and ponding of water in the lower areas and is a factor in the quality of return flows.

There is considerable variation in the losses through the several operations of irrigation systems (2). For instance; canal losses vary from 15 to 40 per cent of the water diverted; wastage from canals and laterals vary from 5 to 35 per cent; farm wastes, from 5 to 10 per cent, and seepage, from 5 to 60 per cent.

Depletion (8) (9) (10) (11) (12) (5)

Irrigation is a consumptive use of water only insofar as water is lost by transpiration and evaporation. Overflows from canals and laterals, runoff from land and seepage, except for the loss due to evaporation, will return either to the surface or ground water. It is estimated that about 74 million acre feet of water applied for irrigation was lost in 1955 through evaporation and transpiration (5).

In the initial stages of the operation of certain projects using surface supplies, storage in the subsurface strata may be almost 100 per cent of the seepage water. As the ground water elevations rise, more and more of the ground water will find its way into surface waters until an equilibrium is reached. At this point the return to the stream may be almost equal to the volume of seepage water. In this case no further permanent storage will occur.

Consumptive use as applied to irrigation includes evapotranspiration losses throughout the system, from the reservoir to the point where the return flow reaches the surface or ground water supply. Evaporation in reservoirs accounts for a substantial portion of this consumptive use and has been estimated to be about 15 million acre feet per year. This is about 35 per cent of the total reservoir capacity available for irrigation. Since this represents a major loss, efforts are being made to reduce it by the addition of monomolecular surface films.

Excessive weed growth along canals and ditches causes significant losses depending upon the type of growth and its magnitude. Phreatophytes are a class of plants known to cause high transpiration losses. Salt cedars which grow along canals in areas of Texas, Arizona, and California are said (11) to consume more than 20 million acre feet of water per year. Willows, cattails and sedges also consume large quantitites of water. These losses are being controlled in a measure by the use of herbicides to reduce the weed growth.

Farm losses by evaporation and transpiration vary widely. The Columbia Basin Interagency Committee made a study of consumptive use (11) by various crops and under three different climatic conditions in the Columbia River Basin Project. This study indicated that losses ranged from 19.8 inches per season in an upland area to 24.8 inches on an exposed southern slope. The average was 24 inches or 2 acre feet per acre per season.

The Geological Survey (8) in an evaluation of the consumptive use of water has estimated stream flow depletions due to agriculture in each of the sub-basins of the Columbia Basin. These depletions vary from 1.25 to 2.20 acre feet per acre. The average was 1.75 acre feet per acre, which compares favorably with the conclusions of the Interagency Committee. The irrigation season in the Columbia Basin is fairly short and evapotranspiration losses are undoubtedly lower than in such areas as the Yuma and Imperial Valleys where seasons are long. The average for the Western States is generally considered to be about two-thirds of the quantity diverted for irrigation.

II. QUALITY CONSIDERATIONS

Water for irrigation must meet special quality requirements. These requirements differ from those of water used for domestic and industrial purposes (13). An excellent water for one may be inferior for the other. For instance: Irrigation water should be relatively high in calcium and magnesium, whereas, a soft water is preferred for domestic use; boron in irrigation water should not exceed 1 to 2 ppm, although these concentrations are not important in domestic water supplies; and silica, nitrate and fluoride are undesirable in domestic water, but in the normal concentrations present no hazard in irrigation water.

Criteria for irrigation water are developed on the basis of salinity, sodium, boron, and bicarbonate concentrations. These are the important factors determining the usability of the water for this purpose.

Salinity and Salt Balance

The growth of plants is affected by high salt content in the soil water. Plants differ in their tolerance to salinity. Electrical conductivity (14) (15) is normally used to measure this concentration.

Water is divided into four groups in relation to the salinity as measured by conductivity in micromhos per centimeter at 25°C (EC x (EC x 10^6). These are designated in terms of C_1, C_2, C_3, and C_4 as follows: (13) (14) (15)

C_1 - Low	Less than 250 micromhos/cm
C_2 - Medium	250 - 750 micromhos/cm
C_3 - High	750 - 2250 micromhos/cm
C_4 - Very High	Above 2250 micromhos/cm

About one-half of the waters used for irrigation in the West comes within the range of 250 to 750 micromhos/cm, which in terms of dissolved mineral solids is about 175 to 500 ppm.

Salts are concentrated in the soil by the removal of water through evaporation and transpiration. The amount of mineral matter taken up by the plants is not sufficient to be significant in the over-all salinity problem. Thus, almost the entire bulk of salts contained in the applied water is contained in the soil solution. To this may be added material which is dissolved from the soil, fertilizers, or soil conditioners. It is necessary that these salts be removed by the drainage water, otherwise both the soil and crops will be adversely affected. Therefore, it is important to maintain a "salt balance" in which the output of salinity equals or exceeds the input. When this situation exists, the salt balance is said to be favorable.

The removal of these salts from the soil requires the use of water in excess of the requirements of the plants. The amount needed varies with the type of soil and the nature of the subsurface strata. This water is called seepage or drainage water and is an important component of return flows, since it contributes the major portion of the salts contained in these flows. It may enter the ground water or may return to the stream by-way-of seepage into drainage systems or ditches.

Plants have difficulty in obtaining water from saline solutions. The characteristic of soils, however, are not adversely affected by high concentrations of salts, if sodium is low in comparison with calcium and magnesium. Sodium renders soils impermeable to air and water, and when wet these soils become plastic and sticky. The effect of sodium on the soil is measured (16) by the "sodium-adsorption-ratio" which is a ratio of sodium ion to calcium and magnesium ions. The following formula (13) is used:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

An SAR of 8 is considered generally satisfactory, 12 to 15 is marginal and above 20 will cause serious consequences and will require special management practices. The application of gypsum (calcium sulfate) to the soil is a management practice used when the "sodium effect" is serious. SAR data must be used in combination with total salt content since the higher the salts the more sodium can be tolerated. This has resulted in a classification of irrigation waters.

Classification of Irrigation Waters

Irrigation waters have been classified on the basis of conductivity and sodium-adsorption-ratio. While there are differences in opinion as to the use of these classifications (17), the one developed by the Department of Agriculture (16) (21) is perhaps the most comprehensive. This classification is diagramed in Figure 2. The slope of the curves in Figure 2 take into account the relationship of the sodium effect to conductivity.

The following interpretation is made of this method of classification:

Salinity factors -

C_1 (low salinity water) can be used on most crops and soils. Normal leaching will serve to remove accumulated salts except in soils of extremely low permeability.

C_2 (medium salinity water) requires a moderate amount of leaching to maintain salt balance. Most crops, except those very sensitive, can be grown without special arrangements for the control of salinity.

C_3 (high salinity water) requires soils of good permeability or the use of special drainage systems and salinity control practice. Crops should be salt tolerant.

C_4 (very high salinity water) is not normally satisfactory for irrigation. If used, soils must be permeable, drainage adequate and crops very tolerant to salt. Considerable water will be necessary for adequate leaching.

CLASSIFICATION
OF
IRRIGATION
WATERS

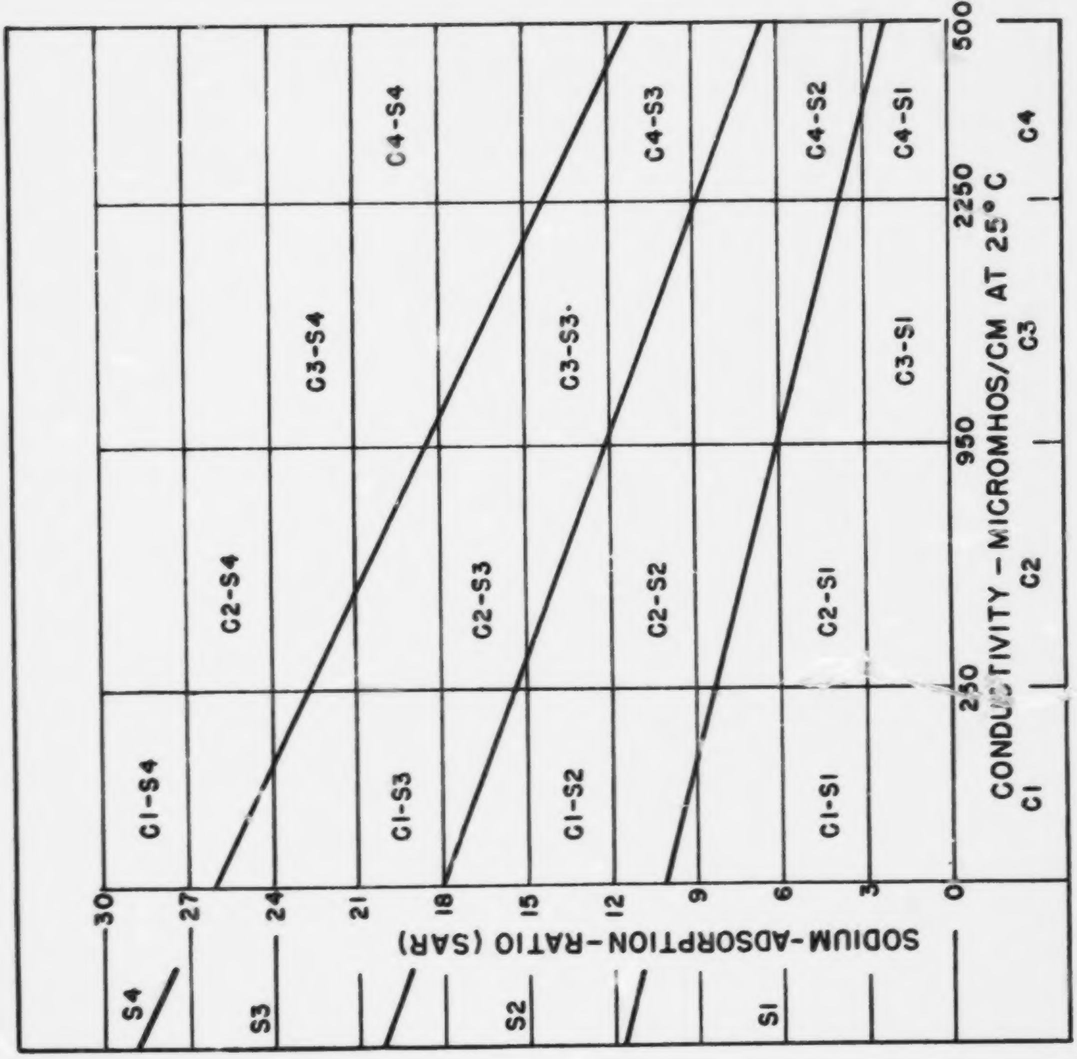


FIGURE 2

Sodium Factors -

S_1 (low sodium water) is usable on most soils. Some very sodium-sensitive crops may be injured.

S_2 (medium sodium water) will cause difficulty on fine soils, especially if leaching is restricted and cation exchange is high. May be used on soils of good permeability.

S_3 (high sodium water) will cause sodium effects in most soils and require special drainage and the addition of organic matter to improve leaching. Cases were the soil is high in gypsum are exceptions. The addition of calcium may be indicated, if it does not produce a salinity problem.

S_4 (very high sodium water) is not satisfactory for irrigation unless the water is low in salinity, and if gypsum or other chemicals can be added without creating a significant salinity problem.

Boron

Boron in certain concentrations is toxic to plants. However, there is a variation in tolerance by species which is influenced by climatic and other factors. The tolerance ranges given in the literature (16) (18) (19) are as follows:

Sensitive crops	0.33 to 1.25 ppm
Semitolerant crops	0.67 to 2.50 ppm
Tolerant crops	1.00 to 3.75 ppm

Sensitive crops include fruits, nuts, and beans; semitolerant crops include cereals, vegetables, and cotton; tolerant crops include alfalfa, sugar betts, and asparagus (13).

Bicarbonate and Carbonate

Bicarbonates in irrigation water tend to render calcium more soluble. When calcium bicarbonate enters the soil an increase in temperature or evaporation may precipitate the calcium as calcium carbonate which tends to hold the calcium in the soil. This is of importance since it keeps the calcium content of the soil high. This reduction of calcium in the drainage water results in an increase in the sodium-adsorption ratio (13).

Some waters contain "residual sodium carbonate" which is defined (20) as the sum of the equivalents of normal carbonate and bicarbonate minus the sum of the equivalents of calcium and magnesium. Those who have studied the carbonate problem have concluded that water containing less than about 66 ppm residual normal sodium carbonate can be safely used as irrigation water, between 66 and 132 ppm is marginal and waters above 132 ppm are not suitable for irrigation.

PART III

RETURN IRRIGATION WATER

I. QUANTITY INVOLVED

The proportion of the irrigation water which returns to the stream or ground water varies over a wide range. It depends largely on the definition of the term "return flow." When applied to surface waters it is usually considered to be that portion of the water diverted for irrigation which returns to the water course from which it was taken. In the case of ground water sources, it is the quantity of irrigation water which enters the ground water strata by recharge or seepage.

Actually the return flow is that portion of the water which is not lost by evaporation or transpiration. On this basis the average quantity of return flow over the Western States is considered to be about one-third of the quantity of water diverted.

The quantity of water diverted for irrigation in 1949 and the estimate for 1956 was given in a previous tabulation (Table II). The estimate for 1956 was 128,000,000 acre feet which is almost 42 trillion gallons. If one-third of this returns to the source, the total quantity of water involved in the return-irrigation-flow problem is about 14 trillion gallons.

There is a wide variation in the quantity of return flow. It is governed by much the same factors as govern the quantity of water diverted for irrigation. These factors are: availability and cost of water; methods of diversion and application; management and control; precipitation; temperature; soil; crops; etc. The variation is between 20 and 60 per cent of the water diverted.

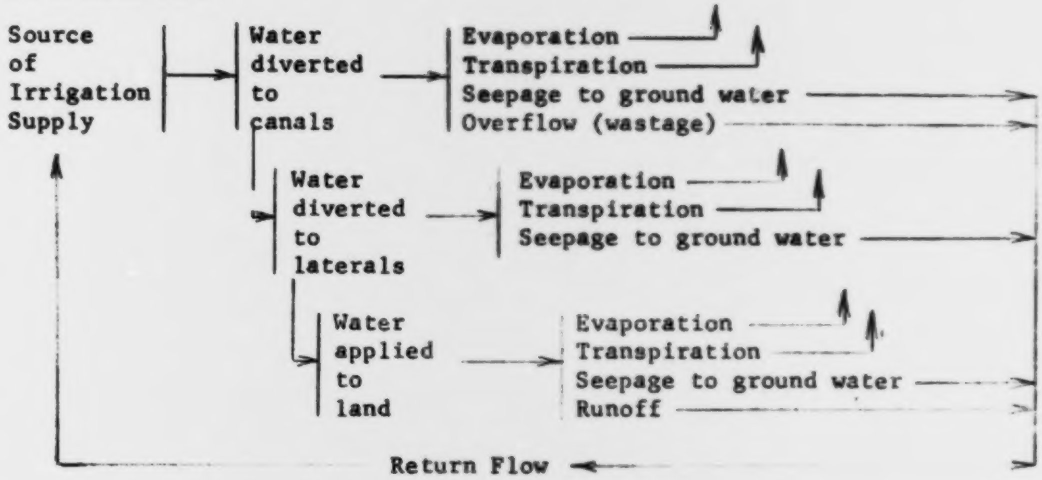
Quantity has a distinct influence on the quality of the return water. Usually the greater the quantity the lower the concentration of dissolved salts. This may not always be true, however, since insufficient water applied at one period may leave salts in the soil which will be removed when more water is applied.

II. SOURCES OF RETURN FLOW

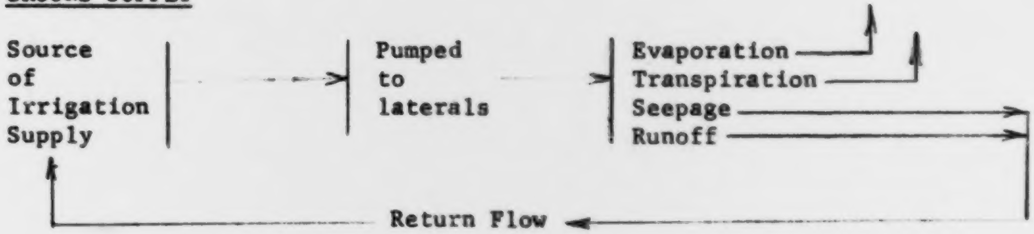
The source of the return flow influences both its quantity and quality. There are three major sources, namely; overflow (wastage), runoff, and seepage (drainage). Two diagrams have been prepared to illustrate the major sources. The first is for a surface water supply

FLOW DIAGRAMS

SURFACE SUPPLY


Source of Irrigation Supply
Water diverted to canals
Evaporation
Transpiration
Seepage to ground water
Overflow (wastage)
Water diverted to laterals
Evaporation
Transpiration
Seepage to ground water
Water applied to land
Evaporation
Transpiration
Seepage to ground water
Runoff
Return Flow

GROUND SUPPLY


Source of Irrigation Supply
Pumped to laterals
Evaporation
Transpiration
Seepage
Runoff
Return Flow

in which the ground water storage elevation has reached an equilibrium and most of the seepage is returned to the surface supply. The Columbia and Yakima Basin Projects are typical of this type.

The second is for a ground water supply where the return flow recharges the ground supply and where little, if any, of the return flow enters surface streams. In some projects of this type drainage wells are provided to return the runoff and, in some cases, drainage to the ground water. Examples of this type of flow exist in certain areas of Idaho and California. With some variations these two diagrams are typical of most irrigation projects.

Overflow is that portion of the water diverted which is in excess of irrigation needs and is used to assure an available supply and in some cases to maintain a water elevation in the canal system sufficient to supply all laterals. It may vary widely in quantity over the season. When irrigation needs are low, the return flows may consist largely of these overflows.

Overflow water probably changes less in quality than that from either of the other two sources. There may be a rise in temperature due to storage in the canals, and evaporation may slightly increase salt concentration. Otherwise, the quality of this flow should be much the same as that of the water diverted.

"Runoff" consists of water applied in excess of that which can be reclaimed by the land. It may be necessary to apply excess water to assure that the water reaches all portions of the land, however excessive application without a legitimate reason is not uncommon. The quality of this water may be distinctly different than that of the water diverted. It may be high in temperature because of being exposed in pools on the land. It may be high in turbidity due to surface erosion, may contain fertilizer elements washed from the surface of the land, or it may be contaminated by bacteria from human and animal excreta.

"Seepage or drainage water" is the water that enters the soil and passes into the subsurface strata. The depth of penetration varies. An impervious strata immediately below the soil or a system of drainage tile may direct the water to surface drains. If the ground water elevation is near the surface an equilibrium may be established where the quantity of water which returns to surface sources is equal to the quantity entering the ground.

The latter situation is presently developing in the Columbia Basin Project. Prior to the development of this project ground water elevations were from 100 to 200 feet below the surface. These elevations are rising generally over the basin and in some of the more completely developed areas have reached the point where ground water is flowing into surface ditches or collecting in low areas from which the water may reach surface water courses. Thus, in these cases seepage becomes a component part of the surface return. This is a situation common to many reclamation project areas.

In those cases where ground water is used for irrigation or where ground water elevations are low, much, if not all, of the seepage water is returned to the ground supply. This is common to areas in California and Idaho.

The quantity of seepage water is equally as variable as the return flow from the other sources. It not only varies by location, but in any given location will vary with the quantity of water applied, climatic conditions, temperatures, and the stage of development of the crop.

As will be shown later in the discussions of specific cases (Appendix A), the salts contained in the drainage water will differ in the proportion of the various ions from that in the applied water. The major changes are in sodium, bicarbonate, sulfate, and chloride content.

III. FACTORS AFFECTING QUALITY

Evaporation and Transpiration

Evaporation and transpiration are the principal factors affecting the quality of return irrigation flow. Salts contained in the irrigation water are concentrated by the removal of water and are retained in this concentrated form in the soil water.

Leaching

The quantity of water applied to the land is important since it must be sufficient to remove the excess salts from the soil. This quantity is known as the leaching requirement and varies from 6 to 25 per cent of the quantity of water applied. This water is usually applied during the irrigation season, but may be added after the crops are removed.

Sources and Significance of Saline and Alkali Soils (21)

Saline and alkali soils may contribute to the quality of return irrigation flows through the removal of salts by leaching. Such soils contain excessive concentrations of salts or exchangeable sodium or both, and require special management practices.

There are very few locations where the weathering of primary minerals in the soils or rocks is sufficient to form a saline soil. Saline soils usually occur in areas that receive salts from other locations.

Water is the carrier. Marine deposits such as the Mancos shales of Utah, Colorado, and Wyoming, and salt intrusion in sea coast areas may cause saline soils. These marine deposits are high in calcium and magnesium sulfate and greatly influence the salt content of return flows in areas where they exist. Salt formations from land locked seas are also an influencing factor.

There are four general types of soils based on salinity-alkalinity considerations (21), namely:

1. Saline soils in which the conductivity of the saturated soil extract is greater than 4000 micromhos per cm at 25°C and the exchangeable sodium percentage less than 15.

2. Saline-alkali soils where conductivity is greater than 4000 micromhos and per cent of exchangeable sodium greater than 15.

3. Nonsaline-alkali soils where conductivity is less than 4000 micromhos and exchangeable-sodium-percentage greater than 15.

4. Nonsaline-nonalkaline soils where conductivity is less than 4000 micromhos and sodium percentage less than 15.

Saline-alkali soils occur in arid and semiarid regions. They are nonexistent in humid regions. In arid regions leachings are not transported far, due to high evaporation and transpiration rates.

Restricted drainage is a factor contributing to salinity, due largely to low permeability or high water table. Surface drainageways are usually poorly developed in low rainfall areas and some basins are entirely without surface outlets to permanent streams. Low permeability may result from unfavorable soil structure or the presence of water-tight layers. Nonsaline soils may become saline as a result of irrigation, since in some cases the need for artificial drains is not recognized.

Cation Exchange (21)

Soil particles adsorb and retain cations on their surface as a result of electrical charges on the soil particles. These may be replaced by other cations in the soil solution (cation exchange). Sodium, calcium, and magnesium are readily exchanged.

Cation adsorption occurs mainly on fine silt, clay or organic matter in the soil. Many kinds of minerals and organic material have exchange properties. The capacity to adsorb and exchange cations is known as "cation-exchange-capacity" (21) and is usually expressed in milliequivalents per 100 gms of soil. There is a relation between the proportion of cations on the soil and the concentration in the soil water.

The process in general is: Calcium and magnesium present in soil water are adsorbed on soil particles up to the limit of the soils capacity. As the soil solution becomes concentrated due to evapotranspiration, the solubility of calcium sulfate, and calcium and magnesium carbonates are exceeded. The adsorption of these cations together with their removal by precipitation leaves a greater proportion of sodium. Under such conditions a part of the adsorbed calcium and magnesium is replaced by sodium.

(The cation-exchange-capacity of a soil is determined by subjecting a weighed quantity of soil to a normal solution of ammonium acetate. Ammonium ions are adsorbed and an equivalent amount of other cations displaced).

Reclaiming Land Having High Salt Content

Another factor which influences the quantity and quality of return irrigation flow, especially the drainage water portion, is that of the reclaiming of land which has accumulated harmful quantitites of salts. This is a situation which may occur in areas where water for irrigation is in short supply for a number of years. An example is the salt build-up in the Rio Grande Valley during 1955 and 1956, which is discussed in Appendix A 1. It may occur also in those areas where the soils naturally contain excessive quantitites of soluble salts.

Such lands, if the sodium content is low, can usually be reclaimed by applying water in the amount of one foot per each foot depth of soil. This quantity of water will normally remove about 80 per cent of the salt. If the soil contains undesirable quantitities of boron, reclamation may require up to 3 feet of water per foot of soil depth since boron leaches slowly.

Soils which contain undesirable concentrations of sodium can be successfully reclaimed by leaching, provided the water has a high calcium and magnesium content in proportion to sodium or provided the upper soil contains gypsum. If these conditions are not met, it is necessary to add gypsum. It may not be economical to reclaim soils of low permeability.

PART IV

RETURN IRRIGATION WATER VS WATER USES

I. USES AND PROBLEMS

There are a number of water uses which may be affected by the quality of return irrigation flows. The major ones considered here are: municipal water supply, industrial supply, boiler waters, rural supply, fisheries as may involve the aquatic environment, esthetic and recreational values as concerned with aquatic growth, the assimilation of sewage and industrial waste effluents, and recharge of ground water.

The effect on these uses will be developed by the analysis of data from specific examples on the basis of seven problems which can and do result from the return irrigation water. These problems are:

Salinity and hardness
Temperature
Turbidity
Nutrients and aquatic growths
Odors and tastes
Nitrates and fluorides
Toxicity (insecticides and herbicides)
Sanitation (bacterial)

Each of the above will be discussed by first presenting specific data to document the problem and then relating these data to specific water uses wherever they may apply. Documentation by means of discussions of specific examples has been appended to the main body of this report. (See Appendices A, B, and C).

II. SALINITY AND HARDNESS

Examples of Salinity of Return Flows (Appendix A)

As previously indicated, successful irrigation requires that a favorable salt balance be maintained in the soil, which means that the salt output must equal or be greater than the input. Except in newly developed irrigation areas or where alkaline soils are involved, the major portion of the salts which accumulate in the soils are those contained in the irrigation water applied. A comparatively small amount may be added by way of fertilizers or soil conditioners and, in some cases, by gypsum applied to correct the sodium ratio. The principal source of the salt content of return irrigation flows, therefore, is that salt contained in the irrigation water. Not only is the return flow water from irrigated land always higher in salt concentration than the irrigation water applied, but there is a shift in the proportion of the various ions present. (See Table IV).

Ten examples are given in Appendix A to illustrate the factors which influence or are related to salinity and hardness of return irrigation flows. These examples are discussed briefly below.

1. Appendix A 1 - Rio Grande and Pecos River.

This example illustrates the effect of irrigation water of high salt concentration on the salinity of the river receiving the return flows. Under average flow conditions (1945), salt concentrations in the Rio Grande increased almost 11 times from 190 to 2060 ppm (Table IX, Appendix A). Hardness as $CaCO_3$ increased from 111 to 631 ppm of which over 500 ppm (79 per cent) was permanent hardness.

The effect of draught and the consequent lack of water for proper drainage is illustrated by the data collected during 1955 and 1956 (Table IX). This resulted in an unfavorable salt balance and the retention of salts in the soil.

A shift is indicated in the proportion of the ions contained in the drainage water as compared to that in the water applied (Table IV). Of the cations, sodium showed the greatest increase, 21.4 times as compared with 5.1 and 7.5 times for calcium and magnesium respectively. These data were taken from the 1945 averages since this was considered to be an average year (Table IX, Appendix A). Of the anions, chloride increased in concentration 129 times as compared respectively with 2.4 and 10.5 times for bicarbonate and sulfate. The shift to sulfate and chloride is normal for drainage water, however, in this case the magnitude of the increase in chloride was exceptional, due to a displacement of very saline shallow ground water under the project.

2. Appendix A 2 - Yakima River Basin

In contrast with the Rio Grande, the concentration of salts in the irrigation water of the Yakima Basin was low (Table X, Appendix A). Water is more plentiful and the return flows do not affect the salinity of the river in the same proportion as when water is in short supply. Nevertheless, the salt content increased about 7 times. Hardness increased from 33 to 134 ppm as $CaCO_3$ of which about 50 ppm (37 per cent) was permanent hardness.

3. Appendix A 3 - Sunnyside Irrigation District

This example demonstrates an area where the salt balance is favorable. The district is located in the Yakima Valley. Salt centrations in the applied water were low.

The average of two seasons results (Table XI, Appendix A) shows that salts in the return flow were 5 times that of the irrigation water in spite of the fact that the quantity of return water was 41 per cent of the latter. Pickup from the soil is therefore indicated.

The change in proportional ion concentration (Table IV) was not as pronounced as in areas where the salt concentration is high. Sodium did increase more than calcium or magnesium, but the shift to sulfates was not pronounced. Percentage-wise chlorides increased considerably (trace to about 15 ppm). However, the concentration of chlorides in the return water was not significant. Hardness increased from 44 to 299 ppm as $CaCO_3$, of which 188 ppm (63 per cent) was permanent hardness.

4. Appendix A 4 - Arkansas River

This is an example similar to the Rio Grande in that the salinity of the applied water is high. Water quantity is apparently not as critical and, therefore, the increase in salt concentration resulting from return flow is not as great. However, there was an increase of almost 6 times between the stations sampled (Table XII, Appendix A).

Sodium again showed the greatest increase, followed by magnesium and calcium (Table IV). Anions increased in the order - chloride, sulfate and bicarbonate. Hardness of the irrigation water was 212 ppm as $CaCO_3$, 75 ppm of which was permanent. Hardness of the river water below the project was 890 ppm of which 650 ppm or 73 per cent was permanent.

5. Appendix A 5 - Sutter Basin

This is an example which directly demonstrates the quality of return flows since the input and output of a specific irrigated area was sampled. The average of the results of a five-year period of study (Table XIII,) Appendix A) shows: Salts increase from 125 ppm to 893 ppm or 7.1 times; calcium 4.6 times; magnesium 6.9 times; sodium 12.7 times; bicarbonate 2.9 times; sulfate 4.6 times; and chloride 40 times (Table IV). The increases in magnesium and chloride are exceptional and noteworthy as being typical of conditions in California irrigation areas. Hardness increased from an average of 72 to 480 ppm as $CaCO_3$, of which 208 ppm (43 per cent) was permanent.

6. Appendix A 6 - Upper Colorado River

This example is another illustration of the quality of return flows as related to an irrigation water of high salt content (Table XIV, Appendix A). The increase in salt concentration was about 5.6 times.

Of special interest is the high magnesium and sulfate increase and the decrease in chloride. The latter situation was not observed

TABLE IV

INCREASE IN SALTS AND IONS AS A RESULT OF IRRIGATION

Location	Number of times greater than in irrigation water						
	Salinity	Ca	Mg	Na	HCO_3	SO_4	Cl
1	10.8	5.1	7.5	21.4	2.4	10.5	129.0
2	7.0	---	---	----	4.3	4.7	3.0
3	5.0	4.4	4.2	8.1	1.8	1.9	-----
4	5.9	3.7	5.5	14.7	1.8	8.6	11.5
5	7.1	4.6	6.9	12.7	2.9	4.6	40.0
6	5.6	4.4	14.0	3.5	1.6	15.0	*
7	7.8	5.3	6.0	17.2	5.2	18.0	8.0

*Decrease

(1) Rio Grande between Otowi bridge and Fort Quitman (Table IX).
(2) Yakima River between Easton and Prosser.
(3) Average of 1943-44 input and output on an irrigation district (Table XI).
(4) Average of 1940-41 data on Arkansas River between Pueblo and Holly (Table XII).
(5) Average of five years of data on input and output of an irrigated area (Table XIII).
(6) Data collected on a short stretch of the Colorado River between Cameo and Grand Junction (Table XIV).
(7) Input and output data of an irrigation project in Boise River Basin (Table XVII).

at any other location for which data were reviewed. A similar increase in magnesium was found to be common in California and to occur in a somewhat lesser extent in other areas. Sulfates appear to be common to the Colorado River drainage area and they are high in concentration in the water of the main river (Table XV, Appendix A).

7. Appendix A 7 - Columbia Basin project

The Columbia Basin project is too new and the quantity of available water so abundant that significant data regarding return flows are not yet available. One of the potential problems involved in this basin is that of ground water elevation and quality. Present data are too meager as yet to interpret the effect of irrigation drainage on ground water supplies. This situation is an example of a new project with good quality water in abundant supply.

8. Appendix A 8 - Boise River

The data presented in Table XVII, Apendix A. shows an increase of almost eight-fold in the salinity of the Boise River. All ions, including chloride, increased substantially. The relative increase in sodium and sulfate ions were highest.

9. Appendix A 9 - San Joaquin and Sacramento

The San Joaquin River is typical of a stream which shows trends toward mineralization. However, the data (Table XVIII, Appendix A) is complicated by dilution from many tributaries and can only be used to indicate the general salinity trend. The ionic concentrations follow the same trends as in most of the cases discussed previously.

10. Appendix A 10 - Sacramento - San Joaquin Delta

The study reported here is an example of the increase in salt concentration resulting from irrigation. The results, however, were somewhat complicated by salt water intrusion and canal leakage into return flows.

Return Water Salinity, Summary

In a previous item of this report the statement was made that the average quantity of return irrigation water is about one-third of the quantity of irrigation water applied. If this is the case, then the salt content of the return flow should be three times that of the irrigation water unless there is a significant quantity of the salts already contained in the soil or subsurface water. In all of the examples (Appendix A) reviewed above (Table IV) the over-all increase was greater than three times. In fact, the lowest was five times.

This means that either the water was used more than once, the return flow was less than one-third of the irrigation flow, or a signficant portion of salts contained in the soil was dissolved by the passage of water.

The other significant change in water quality resulting from irrigation is the shift in the relative concentration of the various ions. The proportion of sodium to calcium and magnesium is always higher in the return water, possibly due to the precipitation of calcium carbonate and to ion exchange. Magnesium remains fairly constant in quantity although changing in concentration.

There are exceptions to the latter statement, especially in certain areas of California and Colorado (Table IV), where magnesium showed a significantly greater increase in concentration as compared to calcium. This was explained (25) as being due to the high percentage of ferro-magnesium minerals in the rocks and soils of the area.

Effects on Water Uses

Appendix C discusses pertinent water quality requirements for domestic supply, boiler waters, industrial supply, and fish and wildlife protection and propagation. The quality of water for irrigation supply was discussed early in this report. These requirements should be used as criteria in interpreting the effect of irrigation on the quality of water for the specified uses.

The magnitude of the salinity due to return irrigation water is usually not sufficient to affect fish and wildlife or the aquatic environment in the receiving water unless the salts contain toxic elements (26) (27) (28) (29).

The principal effects of the salt build-up due to irrigation return flows are on the use of the water for water supply, domestic and industrial, including steam or hot water installations. Water with salts in excess of 500 ppm is not considered satisfactory for domestic supply although water of higher concentration is in use in some areas because it is the only supply economically available.

Such a water cannot be used for high pressure boilers. In fact, the limit of solids in water for boiler pressures in excess of 400 psi is about 50 ppm. The latter, however, would not constitute a reasonable criteria for water affected by return irrigation flows. (Most waters used for high pressure boilers require extensive treatment). The domestic requirement for dissolved solids (500 ppm) appears to be a more realistic criteria on which to evaluate the effects of return irrigation flow salinity.

Table XXVII (Appendix C) gives the requirements for water used by various industrial operations. If industries of the type requiring solids concentrations below 500 ppm are involved, the evaluation must be adjusted accordingly.

Hardness has an even more sifnificant effect than concentrations of solids as regards the use of the water for domestic or industrial supply. Waters are classified as moderately hard, if the total hardness as $CaCO_3$ is between 100 and 200 ppm (Appendix C). Usually water with a hardness above 200 ppm is not satisfactory for domestic or industrial use without softening.

The type of hardness, carbonate (temporary) or non-carbonate (permanent) is an important consideration especially when the water is used in hot water or steam facilities. Carbonate hardness forms a soft scale or sludge which is removable. Hardness due to sulfates and chlorides of calcium and magnesium (permanent hardness) forms a hard scale and causes imbrittlement. While irrigation increases both types of hardness, by far the major increase is in the permanent hardness.

Increasing the hardness of water increases the cost of that water to the user. These costs are in the removal of the hardness compounds in preparation for use. One of the first costs is that of soap or detergents. These compounds are not effective as cleaners until they have been added in excess of the quantity needed to react with the hardness of the water. While the cost of detergents does not increase in the same proportion as that of soaps, an increasing amount is required as the hardness becomes greater. The following tabulation taken from a recent report by Aultman (30) shows the comparison of the annual cost of soap and detergents and the increase due to hardness for a family of five persons.

Hardness as $CaCO_3$ ppm	Soap dollars	Detergent dollars
Soft	32.9	30.2
100	46.0	39.0
200	59.5	48.0
300	73.0	56.5
400	86.5	65.5
500	100.0	74.5

The above tabulation indicates an average increase in cost per 100 ppm of hardness for soap of $13.50 per year and for detergents $9.00 per year.

When the hardness of water exceeds 200 ppm there is a demand for water softening. If community softening is not provided, many households (from one-third to one-half) on the system will purchase or contract for household water softeners. Howson (31) reports that the servicing of these softeners on a contract basis costs the householder an average of $18.00 per year.

Municipal water softening, while less expensive to the individual than household softeners, still involves a substantial additional cost. Estimates made in 1951 including all costs and fixed charges indicated the cost of water softening to be about $31.00 per million gallons ($10.10 per acre foot) per 100 ppm of hardness removed. Seidel (32) in an analysis of water works data in 1955 states that rates charged to to users for municipal water softening are from 20 to 40 per cent greater than for treatment not including softening.

These costs are based on the average hardness situation where permanent hardness is normally less than temporary. The high proportion of permanent hardness resulting from irrigation return flows will substantially increase the cost of chemicals used by either the lime-soda or ion-exchange softening processes. The examples previously discussed show that the proportion of permanent hardness in the return irrigation flow increases as the hardness increases.

The increase in hardness of water used for water supply is therefore an economic problem, the significance of which can be illustrated by the following hypothetical situation using the above cost units. A community is using a stream as a source of water supply. Since the hardness averages 200 ppm, the water is not softened. An irrigation project is located above the city with the result that the hardness of the supply is increased to 600 ppm. Until municipal softening is provided, soap costs to the individual household are increased $54.00 per year or detergent costs, $36.00 per year. Municipal softening when initiated will add $124.00 per million gallons to the cost of water for the community.

Many waters affected by return irrigation flows are not usable for domestic purposes unless diluted by water of lower salt content. In some cases softening is not practical due to the cost and to the complicated nature of the processes required to produce a usable water. Softening processes usually leave sulfates and chlorides of sodium in the finished water. As will be shown later, there are limits to the desirable concentration of these ions. Their removal requires several stages of ion-exchange each of which add to the expense. In these cases, supplying dilution water to reduce the salt concentration may be more desirable and less expensive than water treatment.

The following situation is quoted from a report by Swenson (33). "A recent example is the proposed irrigation project at Canton, Oklahoma, about thirty miles above the Oklahoma City municipal water supply reservoirs. Investigations showed that the increase in mineral content, particularly chlorides, would impair the city water supply. The total solids in the return flow would be at least three times that of the applied water. Total hardness would increase from 300 to 900 ppm and chlorides from 130 to 390 ppm. The increase could be higher than these estimates. It was estimated that the two flood control reservoirs above the project would have to provide a minimum of 40,000 acre-feet a year to dilute the irrigation return flow satisfactorily." Since the return flow in the above cases was estimated as 30,000 acre-feet even with this dilution, the water supply would still be very hard (450 to 500 ppm) and the chlorides would be near the marginal concentration (over 200 ppm).

Method for Estimating Salinity

In the planning for new irrigation projects, an estimate of the salinity effects on the stream receiving the return flow is desirable. The following method for estimating the salinity in the stream below the point of irrigation return flow has been suggested by L. V. Wilcox, U. S. Salinity Laboratory, Riverside, California:

Let ** A - Concentration of salts in water diverted to the Project, ppm.

B - Quantity of water diverted, acre-feet per day*.

C - Surface evaporation from canals and laterals, acre-feet per day*.

D - Concentration of salts in water applied, ppm.

$$D = \frac{BA}{B - C} \qquad (1)$$

E - Quantity of water applied to the land, acre-feet per day*.

$$E = B - C \qquad (2)$$

F - Evapotranspiration, acre-feet per day*.

G - Return flow, acre-feet per day*.

$$G = E - F \qquad (3)$$

H - Soluble salts leached from soil, ppm.

I - Concentration of salts in return flow, ppm.

$$I = \frac{DE}{G} + H \qquad (4)$$

J - Overflow, acre-feet per day*. (This is the quantity of water that dilutes the return flow

IRRIGATION PROJECT

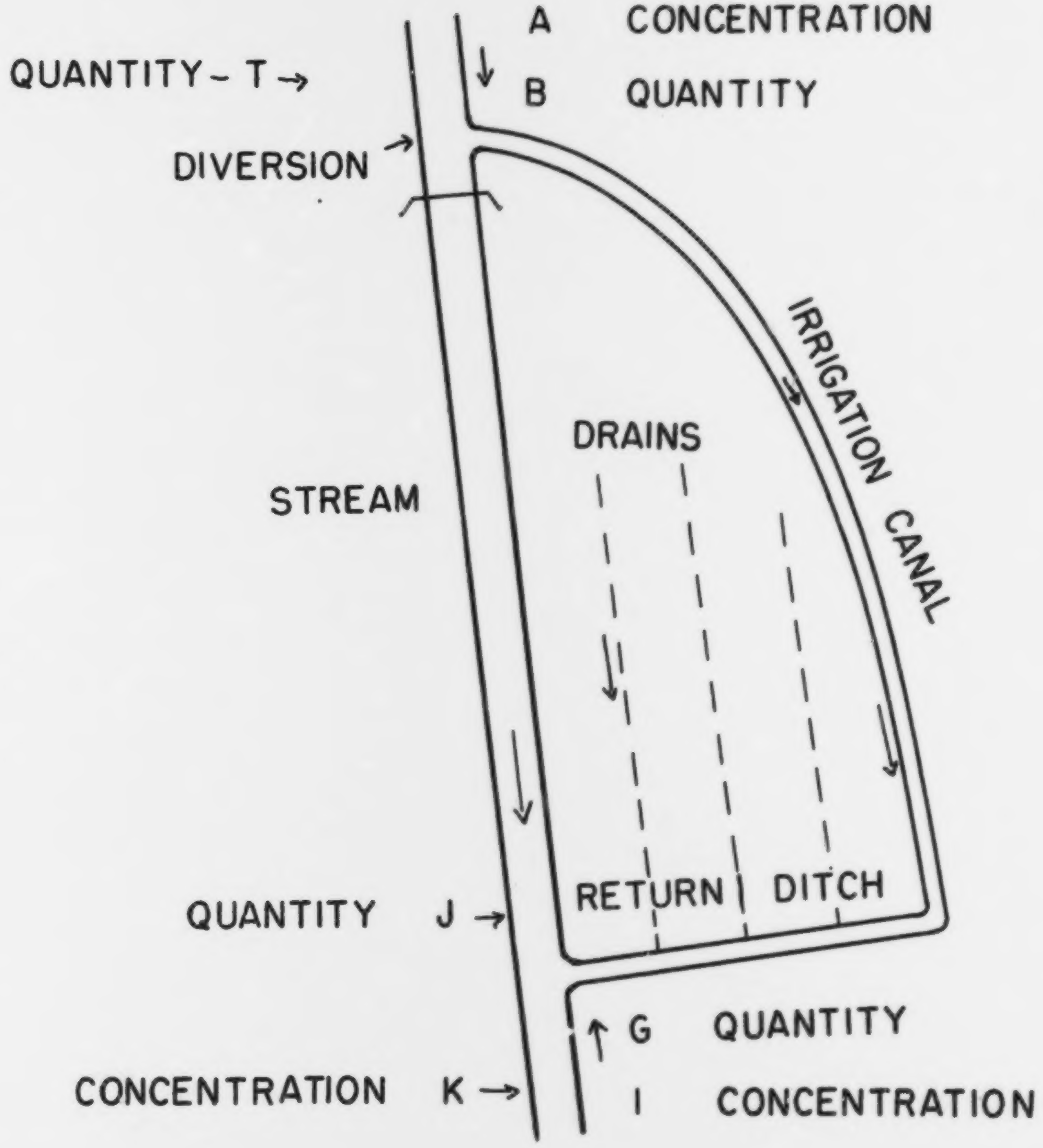

A CONCENTRATION
B QUANTITY
QUANTITY - T →
DIVERSION
IRRIGATION CANAL
DRAINS
STREAM
RETURN DITCH
QUANTITY J →
G QUANTITY
CONCENTRATION K →
I CONCENTRATION

FIGURE 3

or the discharge in the stream at a point just above the drainage return).

T - Total discharge of stream just above point of diversion of irrigation water, acre-feet per day*.

$$J = T - B - C \tag{5}$$

(Assuming that B is the only diversion from the stream and that there are no inflows).

K - Concentration of salts in the stream below the return flow, ppm.

$$K = \frac{(JD) + (GI)}{J + G} \tag{6}$$

*Quantity can be expressed in any desired unit if the same unit is used throughout.

**See schematic diagram, Figure 3.

Notes:

The evaporation rate for the area can best be determined by the use of pans anchored on water surfaces as recommended by the U. S. Weather Bureau.

Evapotranspiration (F) can be estimated from curves given in various text books (34).

Soluble salts in the soil may supplement the salts added by way of the irrigation water. Whether or not this is a significant amount will depend upon the type of soil and the status of the irrigation project. This value can be estimated by field tests using equipment such as the lysimeters used by the University of California Sanitary Engineering Research Laboratory in an investigation of the effects of spreading sewage on soils (35).

Soil is placed in the tank over a bed of gravel. Trays filled with gravel are located at foot intervals and at points such as to intercept about one-third of the water as it percolates through the soil. The soil is saturated with the irrigation water after which the quantity of water which will be applied to the land is applied to the soil in the tanks maintaining a constant head. The soil water is withdrawn, measured and analyzed for salinity. The increase in salt concentration (H) is calculated by subtracting the concentration of salts in the water applied (D) from the results of the analysis. The tank should be covered to prevent evaporation. The results should be reported in the same units of concentration (preferably ppm) as previously used in the estimate.

III. TEMPERATURE

Irrigation Increases Water Temperature

Evidence regarding the effect of irrigation and return irrigation flows on the temperature of a receiving water cannot be completely documented. The only data found to be available which indicates a temperature effect is that presented in Appendix B. The data were collected from thermograph readings in three locations in the Yakima River, Washington. The first station was just below major diversions and above return flows. The second was below most major return flows and the third near the mouth of the river. The water temperature increase at the second station was 9 to 19°F above that at Station 1, while between the second and third the increase was only 1.5°F.

The conclusions drawn from this study was that irrigation and return irrigation flows did have a significant effect on the temperature of the Yakima River and that similar temperature effects may occur in other irrigation areas. It was also indicated that there is a correlation between water and air temperatures.

Significance of Temperature

Temperature is a significant factor involved in the use of water for domestic and industrial purposes and especially in water used for cooling purposes. Temperatures above 55 to 60°F emphasize tastes and odors in water used for drinking purposes and cause it to lose its palatability. Also, the higher the temperature of a water used for cooling purposes, the more water is required.

The major effect of water temperature in many areas will be on the aquatic environment and fishery and in these cases it may be critical. Appendix C indicates the temperature requirements of various types of fish. Certain types are adapted to warm water fish and will tolerate temperatures of 90°F or more, but game fish propagate and develop best at temperatures of 60 to 68°F.

Salmon are perhaps the least tolerant to high temperatures, especially in spawning areas and large numbers of fish will not spawn at temperatures in excess of 63°F. Disease is a critical factor in salmon of the Northwest when temperatures reach 70°F and above. From the example in Appendix B, it will be noted that temperatures in the lower Yakima River often reach 70° and even 80°F during summer months. Columnaris disease is known to be prevalent in this area of the river and has destroyed much of the population of migrant salmon.

There is much yet to be done to document the effect of return irrigation water on the temperature of surface streams. This factor may prove to be of considerable significance.

IV. TURBIDITY AND COLOR

The turbidity of return irrigation flows is the result of erosion of soil and is contained largely in runoff and overflow. Erosion is objectionable from the standpoint of land values as well as water quality and should be avoided. Here, again is a quality of return flows which has received little study.

Examples of the turbidity of return flows are shown in Table V for drains and creeks in the Yakima irrigation areas. While the turbidity of many of the drains was high, the increase in the river was not exceptional because of dilution (from 2 to 14). Appendix C indicates that the turbidity of a satisfactory domestic supply should not be over 10.

From data available it appears that turbidities resulting from return irrigation flows are not normally of major significance. In most cases they can be controlled by lining canals and ditches where velocities are in the scouring range and by reducing runoff by improving application practices.

Color is another problem which has not been given attention. Table XXVI shows the increase in color of water in the Yakima River. The drains and creeks in the Yakima area carry largely return irrigation flows, hence the increase in color is primarily due to irrigation. Table XXV, Appendix C, indicates that a satisfactory water supply should have a color not to exceed 20. Color is also critical for waters for some industries as shown in Table XXVII, Appendix C. Although studies in the Yakima project indicate that return flows may affect the turbidity and color of receiving waters, the significance of these quality characteristics cannot be further evaluated at this time.

V. NUTRIENTS AND AQUATIC GROWTHS

Minerals are essential to the growth of aquatic plants and other organisms such as algae, aquatic weeds, reeds, slime producing bacteria, etc. Three elements are of major importance as nutrients supporting this growth, namely, potassim, nitrogen, and phosphorous. Potassium is usually present in natural waters. Any nitrogen deficiency can be made up by the plant through fixation, but phosphorous seems to be the key limiting element (36) (37) (38). Observations by Sawyer on lakes in Wisconsin have indicated that concentrations of inorganic phosphorous above 0.01 ppm may cause excessive growths. Other investigators (39) (40) indicate that both nitrogen and phosphorous are limiting elements and give 0.3 ppm total nitrogen and 0.015 ppm phosphate as necessary for

TABLE V

TURBIDITY AND COLOR OF RETURN FLOWS

YAKIMA VALLEY

Sampling Point	Turbidity Units	Color Units
Yakima River above diversions	2	4
Teanaway Creek	113	207
Selah drain	10	13
Selah-Moxee Canal	18	36
Moxee drain	239	160
Drain 2, Wapato	93	30
Toppenish Creek	24	33
Corral Creek	41	48
Snipes Creek	178	70
Spring Creek drain	119	66
Grandview drain	45	38
Granger drain	33	38
Sulfur Creek drain	19	21
Sulfur Creek drain & wasteway	39	28
Yakima River below diversions	14	19

the growth of aquatic organisms.

There seems to be a difference of opinion among investigators regarding the contribution of irrigation return flows to the nitrogen and phosphorous content of receiving waters. Goudey (41) describes two examples where the use of nitrogenous fertilizers and sulfur compounds on irrigated land adversely affected water supplies and increased slime growths in distribution systems. Hanley and Bendixen (38) state that "For any great quantity of phosphate to appear in irrigation return waters, the phosphate would have to excape fixation by the growing crops and precipitation in the soil. Nitrates do not seem to be a serious problem in streams receiving irrigation drainage and probably wasteful quantities of phosphate fertilizer would have to be applied to irrigated land in order to contribute major quantities of phosphate to surface waters."

Silvey, however, points out (42) that phosphate may enter the return flows in two ways. First, the precipitated calcium phosphate is converted to soluble phosphate when the soil pH approaches 7.0. Studies by the Texas Research Foundation (42) utilized "tagged" phosphorous and found that 5 mg of phosphorous was removed by percolation from an area to which 25 mg was applied. Secondly, Silvey states that a high percentage of the phosphate utilized by the plant is contained in the leaf. Those leaves are coverted to humus in the soil. This humus containing the phosphorous compounds will float when dry and may be washed into the return flow ditches by the application of water. Also, through oxidation the organic phosphorous compounds in the humus are converted to soluble phosphates.

R. O. Sylvester from preliminary studies of irrigation return flows in the Yakima river, Washington has data which indicates that the nutrient content of water from subsurface drains is higher than that of surface drains. These data indicate that the total phosphorous in water from surface drains varied from 0.9 to 3.9 pounds per acre per year and the total nitrogen from 2.5 to 24 lbs/acre/yr. In subsurface drains the phosphorous varied from 2.5 to 8.9 and total nitrogen from 38 to 166 lbs/acre/yr. On the basis of this limited data it appears that a considerable portion of the fertilizers added to the land are being carried off into the drainage water.

In this same study the nutrient content of the river receiving this drainage increased, but not in the magnitude indicated by the content of the drainage water. This was due to the uptake by aquatic plant life. This plant life was abundant in the drains and streams studied. Much of it was flushed from the streams by the autumn and spring freshets. The decomposition of this material in stream-run reservoirs may cause a build up of nutrient material of significant magnitude.

There is very little information available to support these contentions. However, considering the small amount of nitrogen and phosphorous necessary for the growth of algae and other aquatic plants and the fact that these growth are excessive in return ditches and in streams receiving return flows, there can be little doubt that nutrients are contributed to surface waters by way of these flows. The relative significance of this contribution is yet to be determined.

VI. TASTES AND ODORS

Aquatic growths, organic material, organic decomposition products and certain mineral salts are responsible for tastes and odors in water supplies. Any one or all of these substances may be contained in return irrigation flows.

Silvey (42) (43) has indicated that much of the taste and odor problems of communities on the lower Rio Grande is due to the irrigation projects in that area. Many of these communities obtain water supplies from the canal systems. Nutrients in the return flows support the growth of aquatic organisms as previously discussed. These organisms grow in reservoirs, canals, ditches and streams and contribute considerable organic matter to the water.

Certain of these plants produce amines, esters, fatty acids and aromatic compounds in the course of growth. As the plants die and decay through bacterial decomposition, taste and odor producing compounds are formed. However, Silvey states that "the most common direct contributors of taste and odor are not algae, higher plants or animals, but organisms known as actinomycetes which grow on or in living algae and plants and on the remains of dead animals." He gives in some detail the process by which actinomycetes produce odors and the conditions favorable to their growth. As previously stated, he points to phosphorous as the limiting factor and has developed the curves shown in Figure 4 to support this contention. As a conclusion he states that he "is inclined to offer the association of actinomycetes and algae in different stages as the major cause of tastes and odors in water supplies." If this is a fact, then the contribution of phosphorous by way of return irrigation flows attains added significance.

Salts in certain concentrations also cause tastes in drinking water supplies. For instance, most persons can detect the taste of concentrations above 200 to 250 ppm. The taste becomes objectionable when the chloride concentration exceeds 500 to 600 ppm. Chlorides in this range and above are not uncommon in waters affected by irrigation return flows (Appendix A). Such waters, of course, have other objectionable qualities which in most cases makes treatment mandatory.

The removal of tastes and odors from water supplies is a complex and costly operation. This factor should be taken into account in the development of reclamation projects.

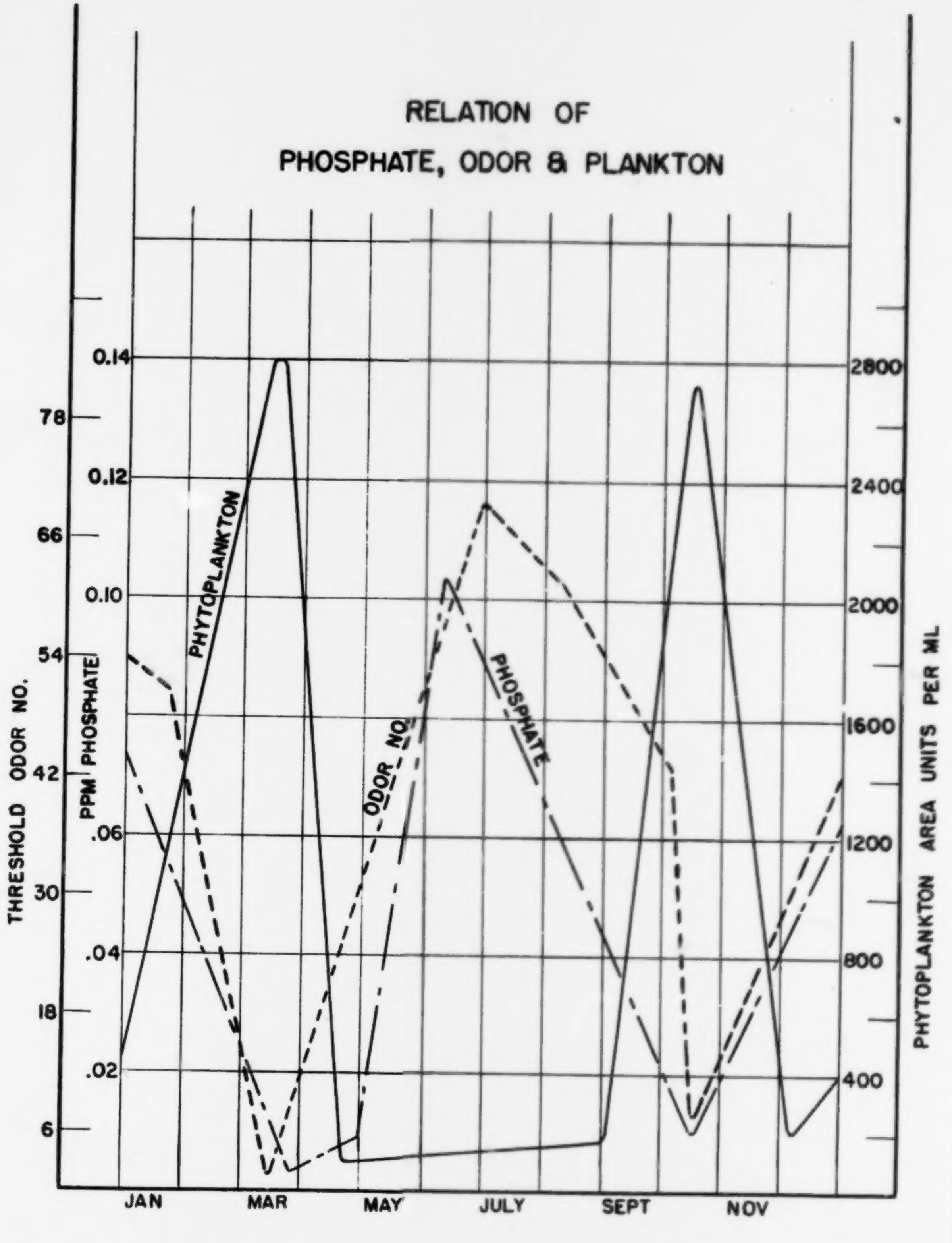

RELATION OF
PHOSPHATE, ODOR & PLANKTON
THRESHOLD ODOR NO.
78
66
54
42
30
18
6
PPM PHOSPHATE
0.14
0.12
0.10
.06
.04
.02
PHYTOPLANKTON AREA UNITS PER ML
2800
2400
2000
1600
1200
800
400
PHYTOPLANKTON
ODOR NO.
PHOSPHATE
JAN
MAR
MAY
JULY
SEPT
NOV

FIGURE 4

VII. NITRATES IN WATER SUPPLIES

Nitrates in water supplies have special significance in that it has been indicated that concentrations in excess of 10 ppm nitrate as nitrogen (about 44 ppm NO_3) is dangerous when the water is used for infant feeding. This concentration of nitrate may cause methemoglobinemia in the infant and can be fatal, depending upon the individual's susceptibility (62).

Ammonia and organic nitrogen compounds are oxidized by soil bacteria to nitrates. Since nitrates are soluble they will be contained in the soil water. A major portion will be utilized by the plants and the remainder will be removed by the drainage water.

Most of the analysis of surface waters containing return irrigation flows reviewed in the course of this study have not indicated high nitrogen concentrations. (Tables 9, 12, 13 and 16, Appendix A). An inspection of thousands of analyses of surface waters influenced by return flows has revealed no nitrate content even approaching the limits given above. However, this does not mean that nitrates are not present in seepage from irrigated land. The general presence of algae and other plants in return ditches and streams receiving return flows has been felt to indicate that the drainage water must often contain high nitrates.

Table VI was prepared from data collected by the California Department of Water Resources from a study in the Oxnard Plain Area, Ventura County, California. The water supply used for irrigation in this country is largely from ground water sources. The nitrate content of two well waters said to be typical of this supply averaged about 3 ppm nitrate. The nitrate content of samples of drainage water collected near the source varied between 21 and 84 ppm. The results may be typical of drainage water in which the nitrates have not yet been utilized by plants.

In spite of the high nitrate content of the drainage in the Oxnard area, it seems reasonable to conclude that nitrate contributed by return irrigation flows will not present a problem in surface water supplies. However, the situation with regard to ground water supplies receiving irrigation drainage may be different as discussed below.

Nitrates in soil water as it drains downward will not be utilized once it escapes the area inhabited by the plant roots. If there is no outlet into surface waters or if the drainage is retained for long periods in the water table, the nitrates will tend to increase along with the other salts.

High nitrates are not uncommon in well waters in many areas. Records of the Washington State Department of Health of water from

TABLE VI

NITRATE CONTENT OF DRAINAGE WATER

OXNARD PLAIN AREA, VENTURA COUNTY, CALIFORNIA

Location	Date	Nitrate as NO_3 ppm
Drain on Oxnard Road	8-4-52	28.7
Ditch near Port Hueneme	8-4-52	21.0
Ditch at Hueneme Road, Bridge 520	6-6-52	49.6
	8-4-52	56.0
	5-12-53	37.2
Revilon Slough	2-27-53	24.8
	1-27-56	56.9
Ditch, Hueneme Rd. west of 101	6-6-52	57.0
	2-27-53	68.1
Ditch West 5th, west of West Rd.	8-4-52	64.5
	1-14-53	63.0
Ditch, Alt 101, S. of Nauman Rd.	8-4-52	74.5
	1-14-53	84.0
Ditch on Pleasant View Rd.	6-6-52	44.6
	8-4-52	74.0

wells in Eastern Washington sampled in 1949 and 1950 show that 167 out of 222 contained nitrates. In 22 of these, the nitrate content exceeded 10 ppm as nitrogen and varied from 11 to 113 ppm. Over half of the wells having a high nitrate content were dug wells and were less than 30 feet deep. However, the well having the highest content was a drilled well over 100 feet deep.

There is no direct evidence that all or even a part of the nitrate in these wells resulted from irrigation drainage. In fact, there is considerable evidence to the contrary in the case of some of the wells in these areas underlined with igneous and lava rocks. It is difficult to document data of this kind on the basis of well water analysis alone. However, some of the wells were in irrigated areas and were less than 20 feet deep and contained in excess of 20 to 25 ppm nitrate as nitrogen (88 to 110 ppm NO_3).

Further indications that return flows contribute to the nitrate content of ground water are contained in well water analysis reported by the California Department of Water Resources (25). Of 115 wells containing nitrates in the Lower San Joaquin Valley, 18 contained more than 10 ppm, and 13 more than 20 ppm nitrates as NO_3. None of the wells examined exceeded the limits for infant use.

While the data available regarding the effect of irrigation on the nitrate content of ground water are far from conclusive, it may be inferred that there is a potential problem concerning which further study should be made. Nitrate determinations should be included in all routine analyses of ground and surface waters where irrigation water is involved.

VIII. INSECTICIDES AND HERBICIDES

There is considerable evidence that insecticides and herbicides applied to plants and land have entered streams and caused extensive fish kills (44) (38) have added to the load of persistent organic chemicals in our water supplies. The fire ant control program of the Department of Agriculture will apply dieldrin and heptachlor to over 30 acres. The production of organic agricultural chemicals has increased 5-fold during the last 10 years (from 125 million pounds in 1947 to 570 million pounds in 1956). However, there is no direct evidence that these chemicals enter waterways by way of return irrigation flows. Hanley and Bendixen sum up the matter in the following quotes (38): "Whatever problems which may exist now or in the future are not necessarily associated with irrigation. It seems likely that insecticide problems are more likely to be encountered in humid areas. The greatest water pollution danger would probably exist when a high-intensity, short-duration rainfall occurs just after heavy application of an insecticide." Actually, however, there is no indication that the problem as it relates to return irrigation flows has ever been investigated.

Many insecticides persist for long periods in the soil, they exhibit strong toxicity to fish and aquatic life (45) (46) (47) (48) (49). (Toxaphene constitutes 61% of the insecticides applied (44), benzene hexachloride - DDT mixture 34%, aldrin 4%, arsenate 1%. Toxaphene is the most toxic, killing trout in concentrations of 0.005 ppm. Dieldrin 96-hour TL_m values range from 0.005 to 0.042 ppm). It seems reasonable to assume that some of this material will be washed into return drains and streams by runoff from irrigation. Whether or not the concentration is sufficient to affect the aquatic environment would depend upon the situation and requires further investigation.

Copper sulfate and other types of chemicals are used in canals and ditches to reduce algae and weed growth. In the Columbia Basin Irrigation Project 40 to 50 tons of copper sulfate per season is used for algae control. Much of the copper in this case will collect in the muds of Potholes Reservoir, which is used as a fishing and recreation area. To date there are no reports of damage to aquatic life.

During recent years, numerous new chemicals have been developed for weed control. Some, but not all of these exhibit toxic effects on fish and other aquatic organisms (45) (48) (50) (51). Flaigg in 1953 reported (3) that there were no ill effects from the use of herbicides for weed control and salt cedar destruction by the Bureau of Reclamation. However, since these chemicals are toxic (52) and since they are applied in such a manner as to have easy access to return irrigation flows, the only conclusion that can be made is that herbicides used for the control of weeds in irrigation projects present a potential toxicity problem in receiving waters. This is a situation which is not easily assessed and which will require a more direct study than can be obtained by depending upon reports of fish kills.

IX. SANITATION - BACTERIOLOGICAL

The major sources of contamination of return irrigation water by bacteria are:

1. Irrigation water which has been contaminated by sewage bacteria prior to its application. Numerous surface streams which are diverted for irrigation receive either raw or treated sewage prior to diversion. The Yakima Basin presents a typical example of this situation. A survey in 1951 (53) indicated an average bacteria concentration at the entrance to the Sunnyside diversion of 28,210 per 100 ml. The sources of this contamination are the effluents from municipal sewage treatment plants which discharge to the river above the diversion.

2. Rural septic tanks, cesspools, and refuse dumps, the effluent and seepage from which may enter ditches or be carried by irrigation drainage into ground or surface waters.

3. Runoff of land which may flush animal excreta and other contamination into return flows. Typical of this source of contamination is a situation which existed in the Minidoka area, Snake River Basin, Idaho. There are no surface flows in this area. Water for irrigation is pumped from the ground. Runoff and seepage are collected and returned to the underground basalt formations by way of drainage wells. There is a rapid movement of underground water in this area and the drainage wells are cased only through the over-burden. Significant bacterial concentrations are found in shallow domestic wells in the area.

The travel of bacterial contamination in surface canals is shown on Figure 5, taken from the Yakima River Report of the Washington Pollution Control Commission (53). The Wapato irrigation area where this study was made is self-contained. Water from the main canal is diverted into four laterals below which are five drains for return flows.

The MPN (most probable number of bacteria per 100 ml) at the diversion is 28,210. This is reduced largely by die-away to 6770 in 14 miles and to 5750 in 20 miles. Drain 1 which receives return flow showed an MPN of 1600; drain 2, 7000; drain 4 1580; and in the main drain 4290. While in all cases there was a reduction or improvement over the bacterial concentration in the water applied, the results show the effect of the contaminated irrigation water on that of the return flow is probably due to overflow or run-off into the drains.

Bacteria entering the soil are not concentrated as are salts. In fact, the soil does an excellent job of removing the organisms. The travel of bacteria in soil and underground strata has been extensively studied by many investigators. The results of these investigations vary widely. This is to be expected because of the variation in the conditions of the experiments. Some investigators use polluted waters, others strong sewage, while other investigations involved treated or diluted sewage. These reports indicate that bacteria will travel in the ground distances varying from 10 to 800 feet. (Numbers from References on bacterial travel).

There is apparently very little lateral movement of bacteria until the ground water is reached. Movement in the ground water is

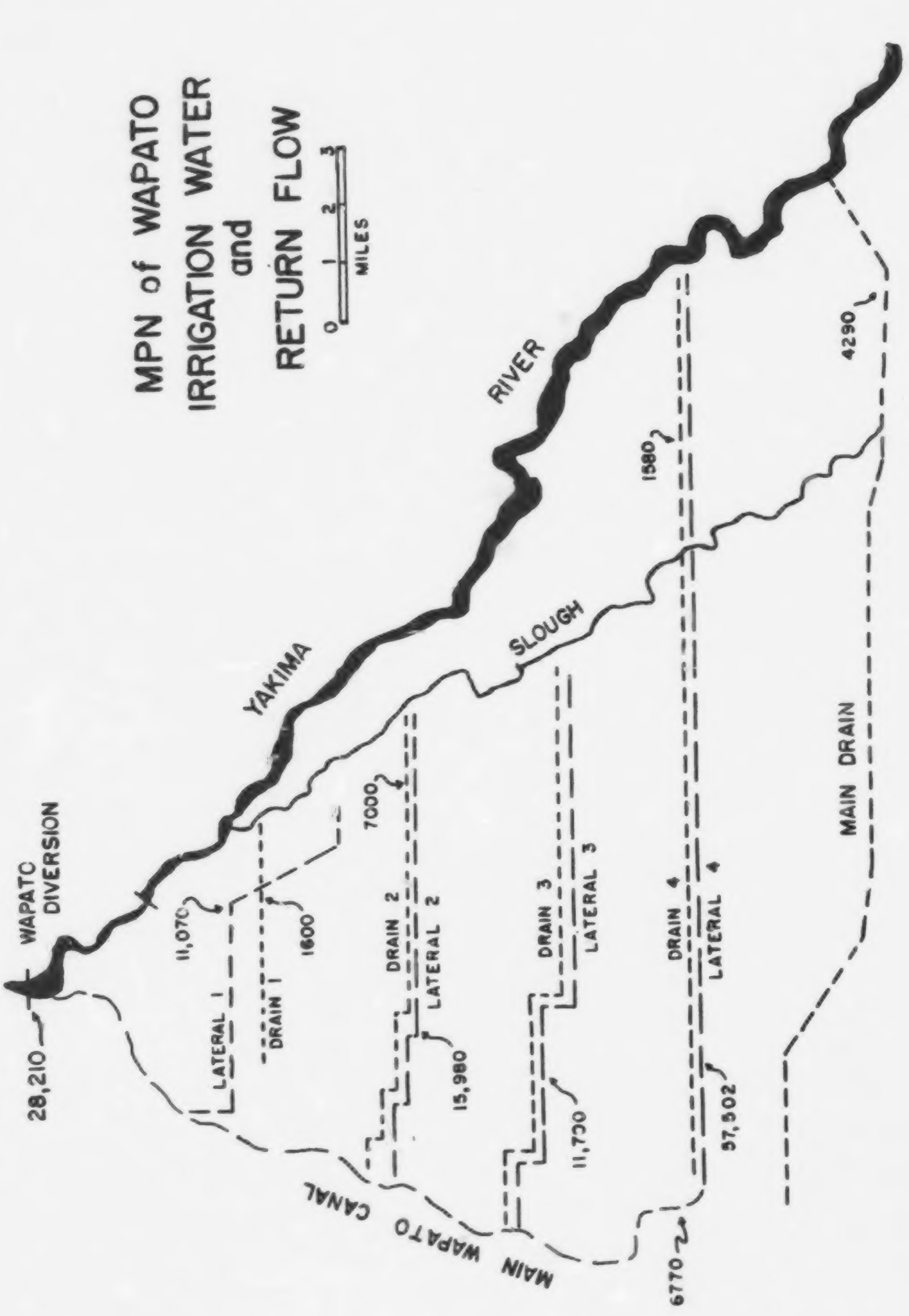

MPN of WAPATO
IRRIGATION WATER
and
RETURN FLOW
0 1 2 3
MILES
WAPATO DIVERSION
28,210
YAKIMA
RIVER
SLOUGH
MAIN WAPATO CANAL
LATERAL 1
DRAIN 1
11,070
1600
DRAIN 2
LATERAL 2
7000
15,980
DRAIN 3
LATERAL 3
11,700
DRAIN 4
LATERAL 4
57,502
6770
1580
4290
MAIN DRAIN

FIGURE 5

naturally in the direction of flow. Bacteria are removed by straining, sedimentation on soil particles, and die-away.

The most recent and extensive studies of bacteria travel in soils and ground water have been made in California in connection with the recharge of underground aquifers (54) (55) (56) (57) (58) (59). Briefly, the conclusion reached by the California experiments with the travel of bacteria in the fine soils studied are: (56)

1. A definite inverse relationship exists between coliform count and depth of soil.

2. The disappearance of bacteria with depth is very rapid. The bacterial count dropped below the Public Health Service standard for potable waters (1 coliform per 100 ml) in depths varying from 4 to 7 feet.

3. The number of bacteria penetrating one foot or more of soil is independent of the number in the applied water.

Experience with coarse soils lead to the conclusion that it was not "practical to write any specifications of the minimum distance from the ground surface to the water table which should be maintained in order to prevent coliform bacteria from reaching the ground water."

These tests would seem to indicate that with fine soils, unless the water table is near the surface, there is little chance of contamination of ground water supplies by drainage water from irrigation. With coarse soils there is a chance that some contamination may reach the ground water, but that the bacterial concentration will be greatly reduced.

The California experiments also included a study of the travel of coliform in the ground water. The results are not completely comparable to the travel of irrigation water which reaches the ground water because diluted sewage was used in the studies and introduced into the aquifer under pressure. Bacteria would not be expected to travel as far in the same media when introduced by way of seepage and, therefore, the conclusions will be on the safe side. The conditions, however, were more nearly similar to those where return flows are returned to the aquifer by drainage wells as in the Idaho area previously mentioned.

The pertinent conclusions reached were: 1. Bacteria moved more slowly than the transport water; 2. The rate of movement was greatest in the direction of normal ground water flow; 3. The most distant point of coliform travel was 100 feet in the direction of normal flow and bacterial travel beyond this point was negligible; 4. Prolonged recharge did not cause bacteria to extend beyond their initial distance of travel; 5. The rate of bacterial removal with distance is a function of the aquifer characteristic known as filterability.

In view of the experience with both spreading and direct introduction of contaminated water into the aquifer, it was concluded that unless the spreading would be on a thin coarse soil over a fissured strata, the ground water contamination would not be a serious matter. The reasons for this conclusion given in the California reports are as follows (56): 1. There is a drastic reduction in organisms occurring during infiltration; 2. There would be a tendency for dilution; 3. Since no gradients can be imposed by percolating water, the limited initial travel of bacteria in the studies may be interpreted as evidence of the small importance of sewage spreading as a public health hazard.

With this experience as a basis, it seems reasonable to conclude that under most conditions return irrigation water (which will normally contain a much lower concentration of bacteria than the media used in the California experiments) does not constitute a serious public health problem by way of the contamination of ground water supplies. There are naturally exceptions to such a conclusion and local conditions must be taken into account in a determination of hazards in specific cases. Among the most likely exceptions are water supplies from shallow wells near the irrigation area and the introduction of the contaminated water into fissured strata or strata of coarse gravel. In these cases, straining, precipitation and dilution may not be adequate to remove the initial organisms.

Regrowth and die-away is another factor which may influence the general conclusion given above. Coliform bacteria will eventually die out completely, however, they may survive for long periods depending upon the conditions available for growth. These conditions have been the subject of considerable study and will not be discussed here (57).

APPENDIX A

APPENDIX A

SALINITY AND HARDNESS

The following examples will illustrate the increase in salinity, the change in the composition of mineral constituents, salt balance, and the effect of the lack of water for proper drainage, all of which are related to the quality of return irrigation water.

RIO GRANDE AND PECOS RIVERS

Increase in Salinity

The Rio Grande and its tributary, the Pecos River, are classic examples of the increase in mineral content due to the use of water for irrigation (60). These rivers have been studied rather intensively since the U. S. Salinity Laboratory, Riverside, California, started its salt balance investigation in 1932. This is a situation involving large concentrations of salts. The investigation of the Rio Grande problem was given special recognition in February 6, 1950, when the Subcommittee on Hydrology, Federal Interagency River Basin Committee established a network of stations on Western rivers, specifically to study the quality of water for irrigation. Fourteen stations were established on the Rio Grande River system, four of which were on the Pecos. Figure 6 and Table VII show the approximate location of these stations.

Sampling was started in 1951 by the Geological Survey and the results reported in G.S. papers (22) (23) (24) (25). Table VIII shows the runoff in acre-feet per year and the salinity at each station for the four-year period 1951 through 1954. The salinity is reported in 1000-ton units of dissolved solids and the concentration as the weighted average in ppm.

The water of this river system is used several times for irrigation. Salt concentrations increase as the water proceeds downstream. Low flows at certain locations indicate that much of the water is either lost by evaporation and transpiration or is retained as ground water. In these cases, the salt content is highest showing that the return flows from irrigation are largely composed of seepage. The Pecos River is very high in mineral content as it enters the lower river. Tributaries below the Pecos tend to dilute the salts and lower their concentration in this section.

The bulk of salt carried by the river and the salt balance is shown in Table VIII. The year 1951 appears to be an average year. The salt concentration (1951) in tons of dissolved solids is plotted on Figure 7 for the 14 stations on the Rio Grande and Pecos River. There is evidence of salt retention in the areas represented by stations 48

SAMPLING STATIONS
RIO GRANDE & PECOS
RIVER

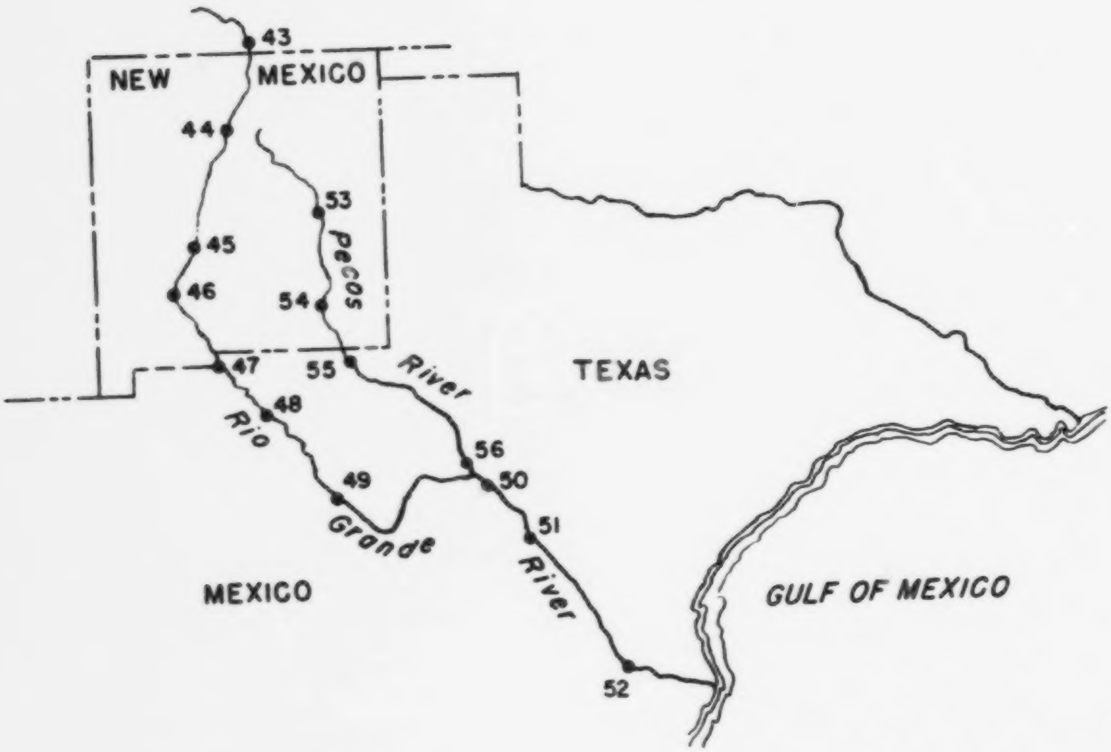

43
NEW MEXICO
44
53
Pecos
45
46
54
47
55
River
TEXAS
48
Rio
56
50
49
51
Grande
River
MEXICO
GULF OF MEXICO
52

FIGURE 6

TABLE VII

SAMPLING POINTS RIO GRANDE AND PECOS RIVERS

No.	Location Near	Approximate Mileage Between Stations	From Gulf
	Rio Grande River		
43	Lobatos, Colo.	0	1420
44	San Ildefonso, N. M.	135	1285
45	San Marcial, N. M.	140	1145
46	Elephant Butte Outlet	45	1100
47	El Paso, Texas	130	970
48	Fort Quitman, Texas	80	890
49	Upper Presidio, Texas	160	730
50	Langtry, Texas	250	480
51	Eagle Pass, Texas	115	365
52	Roma, Texas	225	140
	Pecos River		
53	Alamorgorde, N. M.	0	1035
54	Artesia, N. M.	150	885
55	Orla, Texas	85	800
56	Comstock, Texas	310	490

TABLE VIII

Salt Content, Rio Grande and Pecos Rivers

River	Sample: Point No.	1951* Runoff 1000 a.f.	1951* Dis. Solids ppm	1951* Dis. Solids 1000-ton	1952* Runoff 1000 a.f.	1952* Dis. Solids ppm	1952* Dis. Solids 1000-ton	1953* Runoff 1000 a.f.	1953* Dis. Solids ppm	1953* Dis. Solids 1000-ton	1954* Runoff 1000 a.f.	1954* Dis. Solids ppm	1954* Dis. Solids 1000-ton
Rio Grande	43	80	235	28	448	167	103	135	248	46	72	225	24
	44	395	242	130	1378	188	358	549	237	176	451	237	144
	45	118	567	91	685	349	322	256	558	194	104	781	110
	46	451	588	360	543	422	312	554	443	333	27	6900	253
	47	273	924	342	284	740	286	269	753	275	102	1015	141
	48	50	2605	177	11	3960	59	25	2740	93	13	1415	25
	49	49	1635	109	13	3960	7	---	----	---	40	570	31
Pecos	53	149	1680	340	126	1590	272	98	1890	252	67	2190	198
	54	139	3270	619	110	3220	484	80	3530	385	74	3510	354
	55	110	4580	687	49	6780	455	7	9760	99	64	6790	592
	56	147	2530	506	104	2350	332	85	1890	218	2019	438	1200
Rio Grande below Pecos	50	864	593	694	694	529	498	336	604	276	953	565	540
	51	1311	643	1146	998	583	791	669	506	460	4203	443	2528
	52	1990	555	1500	1094	597	888	925	445	560	2245	389	1187

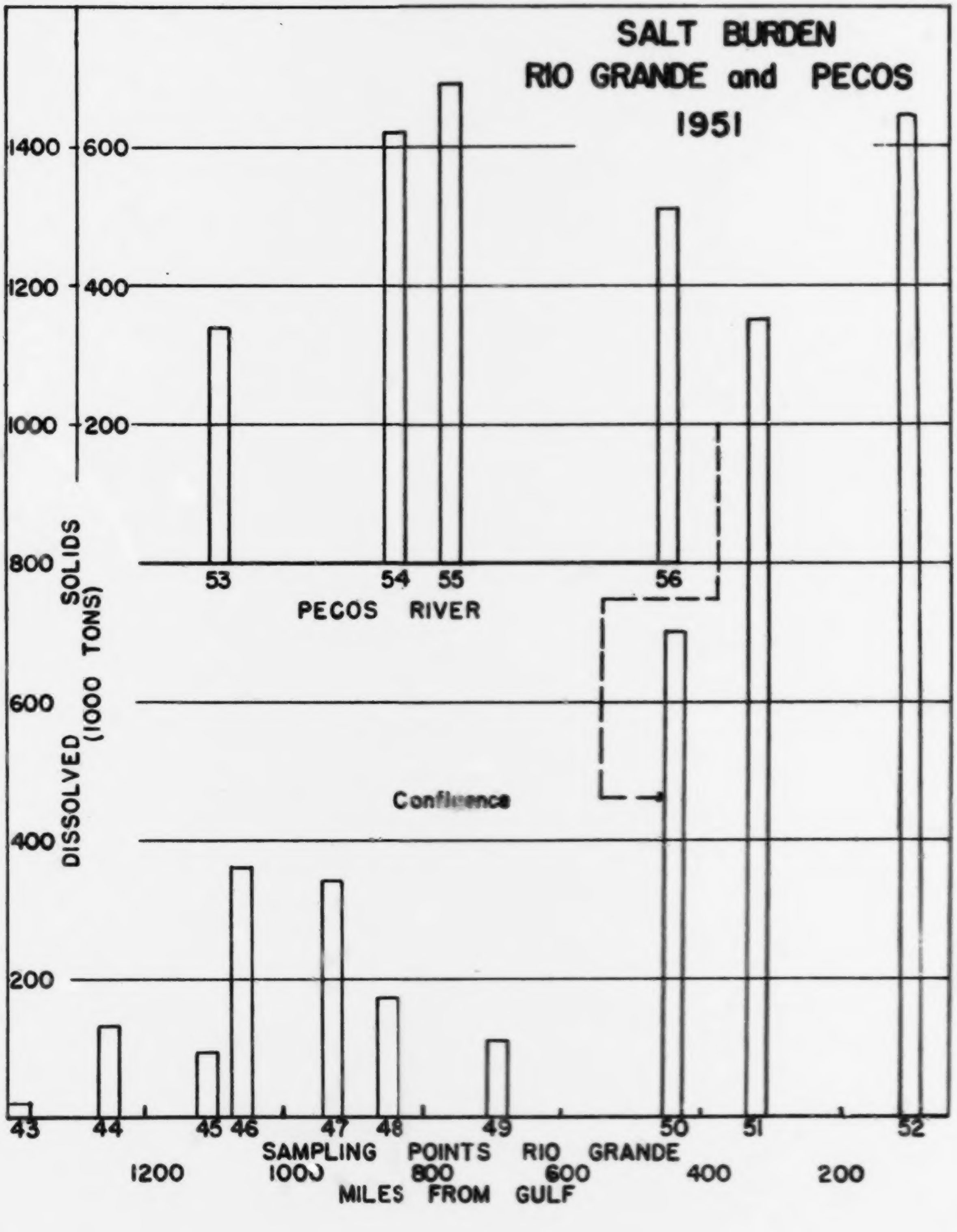

SALT BURDEN
RIO GRANDE and PECOS
1951
1400
1200
1000
800
600
400
200
600
400
200
DISSOLVED SOLIDS (1000 TONS)
53
54
55
56
PECOS RIVER
Confluence
43
44
45
46
47
48
49
50
51
52
SAMPLING POINTS RIO GRANDE
1200
1000
800
600
400
200
MILES FROM GULF

Figure 7

and 49, however, it may be that return flows do not enter the river in these areas.

The year 1954 was exceptional in that during the winter months there was almost no flow in the river at several stations (48 and 49). A severe flood occurred in June. During this month over 1,500,000 tons of salt were carried by the river at station 51. Undoubtedly salts accumulated in the soil were at least partially removed by flood waters.

Effect of Drought on Salinity

The two years which followed the 1954 floods were periods of drought when water for irrigation was not available in sufficient quantity to maintain a favorable salt balance in certain areas of the Rio Grande Project. This is demonstrated by a special salt balance study made by the U. S. Salinity Laboratory, Riverside, California, in cooperation with the International Boundary and Water Commission and the Geological Survey. The data involved in this discussion were taken from unpublished reports (38) (61). The results of a similar study in 1945 are included for comparison with the data from 1955 and 1956.

The section of the river under survey is that between Otowi Bridge near Santa Fe, New Mexico, and Fort Quitman on the Texas-Mexico boundary (Figure 8). There are irrigation projects along much of this section of the river, however, the salt balance studies are being made in the "Rio Grande Project" between Caballo Dam and the El Paso-Hudspeth Country line above Fort Quitman. Figure 8 shows the location of the seven sampling points used for these studies. They are described as follows:

SP 1 - Otowi Bridge near Santa Fe.
SP 2 - San Marcial at upper end of reservoir.
SP 3 - Elephant Butte Dam at lower end.
SP 4 - Caballo Dam, upper limits of Rio Grande project.
SP 5 - Leasburg Dam.
SP 6 - El Paso
SP 7 - Fort Quitman just below lower limits of Rio Grande Project.

The discharge at Otowi Bridge for the year 1945 was slightly above the average of the twenty-two years of record, 1,131,550 and 1,019,000 acre-feet per year respectively. Discharges during 1955 and 1956 were 43 and 35 per cent of the average at SP 1, Otowi Bridge. The flow at SP 7 was almost nil during these two years.

Table IX shows the weighted mean concentration of salts at each of the seven stations for the years 1945, 1955 and 1956. The

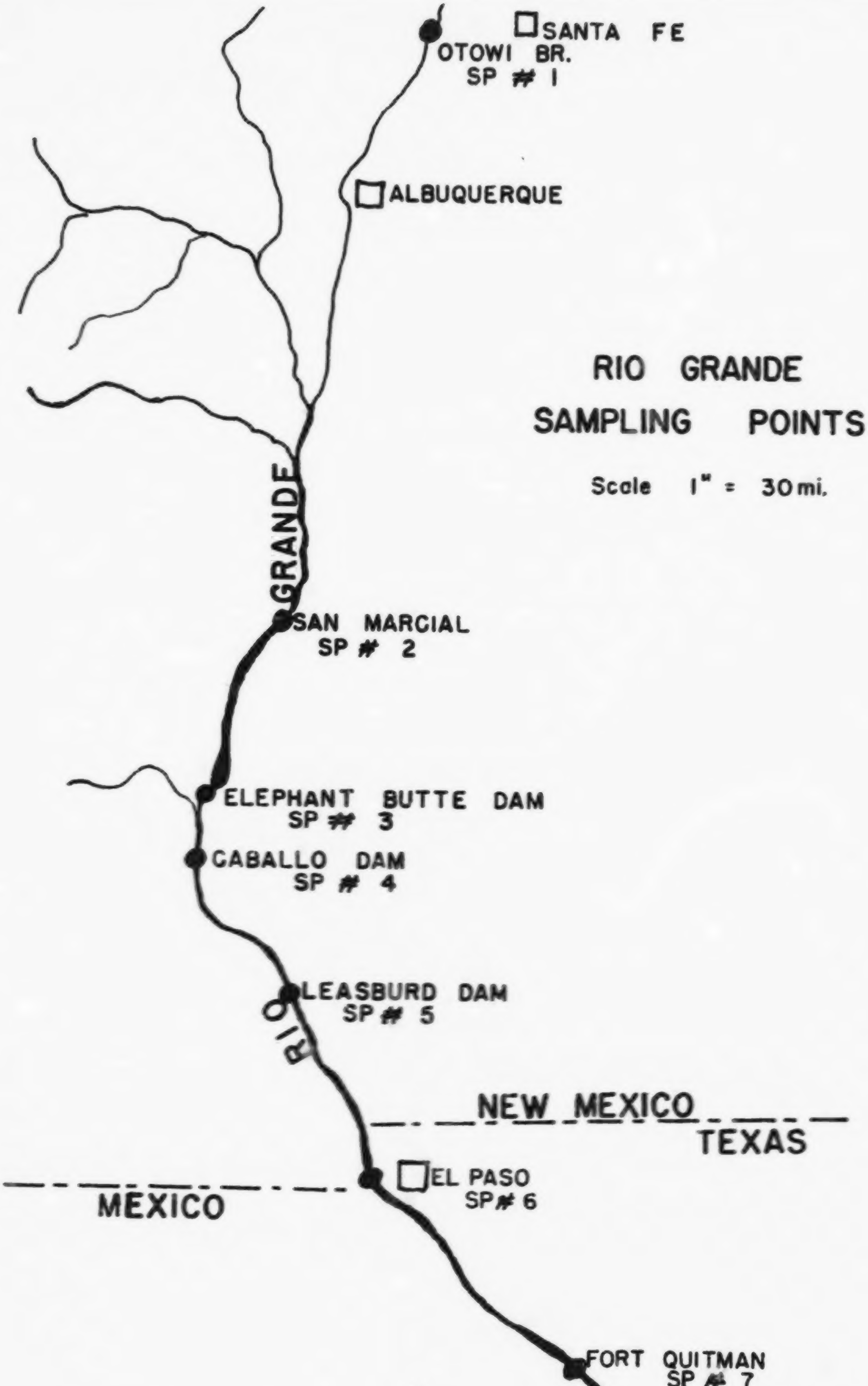

SANTA FE
OTOWI BR.
SP # 1
ALBUQUERQUE
RIO GRANDE
SAMPLING POINTS
Scale 1" = 30 mi.
GRANDE
SAN MARCIAL
SP # 2
ELEPHANT BUTTE DAM
SP # 3
CABALLO DAM
SP # 4
LEASBURD DAM
SP # 5
RIO
NEW MEXICO
TEXAS
EL PASO
SP # 6
MEXICO
FORT QUITMAN
SP # 7

Figure 8

TABLE IX

RIO GRANDE - DISCHARGE AND MINERAL CONTENT
(Weighted Mean Concentrations)

Item	Sampling Points - Nos.						
1945	1	2	3	4	5	6	7
Discharge, 1000 ac.-ft.	1132	814	840	883	814	569	208
Conductivity	280	567	662	740	778	1210	3200
Dissolved Solids ppm	190	380	430	480	510	802	2060
Calcium "	34	51	58	63	65	89	175
Magnesium "	6.0	9.7	12.0	13.1	13.7	18.8	44.6
Sodium "	16	53	64	74	79	146	461
Bicarbonate "	52	75	80	86	85	114	123
Sulfate "	47	112	149	156	169	254	497
Chloride "	5	32	35	50	54	122	644
Nitrate	tr.	1	tr.	0.6	0.6	0.6	0.6
Dissolved Salts - 1000 tons	294	420	492	578	565	620	582
1955							
Discharge, 1000 ac.-ft.	437	264	212	219	191	67	6
Conductivity	393	1190	1374	1359	1389	1521	838
Dissolved Solids ppm	258	852	948	925	948	1015	551
Calcium "	48	120	109	104	114	110	46
Magnesium "	9.4	22.9	22.8	23.6	22.5	24.3	11.3
Sodium "	23	123	161	158	156	194	125
Bicarbonate "	162	---	169	154	188	184	165
Sulfate "	61	---	410	381	365	392	136
Chloride "	9	---	113	132	135	170	111
Nitrate "	1.2	---	0.6	0.6	2.5	0.6	1.2
Dissolved Salts - 1000 tons	153	306	274	276	246	92	4
1956							
Discharge, 1000 ac.-ft.	359	136	253	246	210	57	6
Conductivity	367	998	1205	1258	1290	1539	778
Dissolved Solids ppm	243	675	825	852	875	1050	515
Calcium "	43	85	92	93	101	111	76
Magnesium "	8.3	19.3	22.5	22.7	22.5	25.0	15.7
Sodium "	23	110	138	149	149	194	80
Bicarbonate "	149	---	168	179	185	198	229
Sulfate "	54	---	338	331	338	404	85
Chloride "	8	---	99	118	122	160	108
Nitrate "	0.6	---	tr.	tr.	0.6	0.6	0.6
Dissolved Salts - 1000 tons	115	125	283	286	250	82	4

concentration of total dissolved salts for the three years are plotted on Figure 9. Table IX also shows the total weight of salts carried by the river at each station. There are plotted on Figure 10.

Figure 9 shows the gradual increase in mineral salts concentration during the normal flow period (1945) when water was available for removing the salts from the soil. The output of salts exceeded the input as indicated on Figure 10. Return flows were responsible for much of this increase in concentration, which was almost 1000 per cent. The quantity of discharge at the lower station was about one-third of that available in the stream above the projects.

The situation was different during the low flow years of 1955 and 1956. The use of water during this period was almost completely consumptive. Concentrations of salts, while contained in a lesser volume of water, did not reach the magnitude of the more normal period. The increase in concentration was only 300 per cent as compared with 1000 per cent in 1945. However, from Figure 10 it is apparent that almost the entire bulk of salts added by way of the irrigation water remained on the lands of the area during these years. It is apparent that the salt balance is unfavorable and, if the situation continues, the value of the lands for crops will be significantly lessened.

Another factor which may be significant in view of future uses of the water is that these accumulated salts will be contained in future discharges when the drought is broken. The magnitude of the problem created will depend on the extent of the rainfall and the season during which it occurs. During each of 1955 and 1956 almost 300,000 tons of mineral salts were retained in the area.

Change in Mineral Characteristics

Of equal, if not greater importance, to the use of water containing return irrigation flows is the change in the proportions of the major mineral constituents. Table IX shows the weighted mean concentration in ppm of the major positive and negative ions at each of the seven stations for the three periods. The data for 1945 were used to compute the per cent calcium, magnesium and sodium based on total cations and bicarbonate, sulfate and chloride based on total anions. The percentages are shown in Figure 11.

Sodium showed the greatest percentage increase, although all cations increased in concentration. The sodium content at Fort Quitman at the lower end of the project (Station 7) during 1945 was 461 ppm compared to 16 ppm at Station 1.

Hardness as calcium carbonate increased from 110 to 620 ppm. While this is a considerable increase, it is even more significant from the standpoint of water supply that the increase was almost

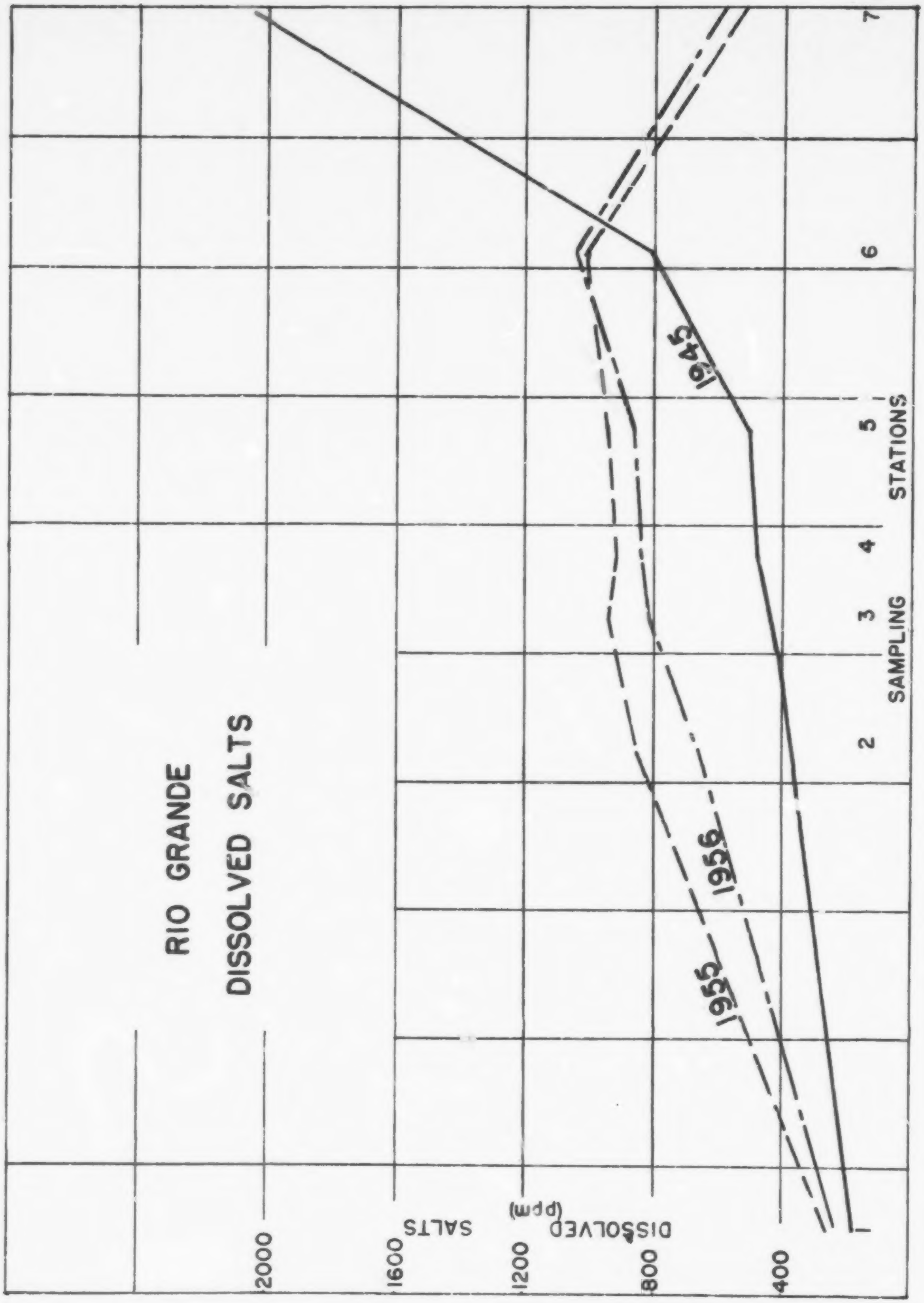

RIO GRANDE
DISSOLVED SALTS
DISSOLVED SALTS (ppm)
2000
1600
1200
800
400
SAMPLING STATIONS
1
2
3
4
5
6
7
1945
1955
1956

Figure 9

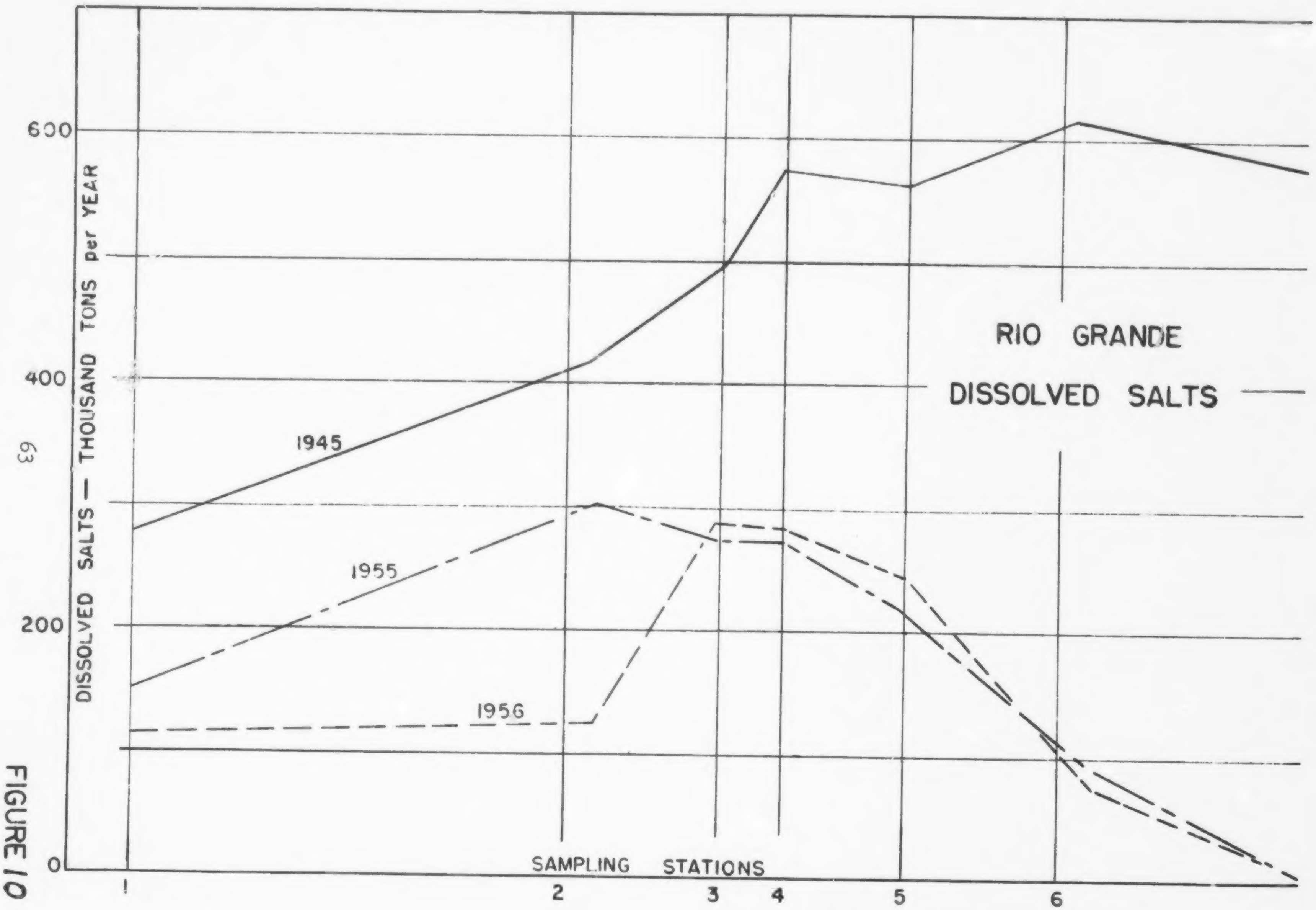

RIO GRANDE
DISSOLVED SALTS
DISSOLVED SALTS — THOUSAND TONS per YEAR
600
400
200
0
1945
1955
1956
SAMPLING STATIONS
1
2
3
4
5
6

FIGURE 10

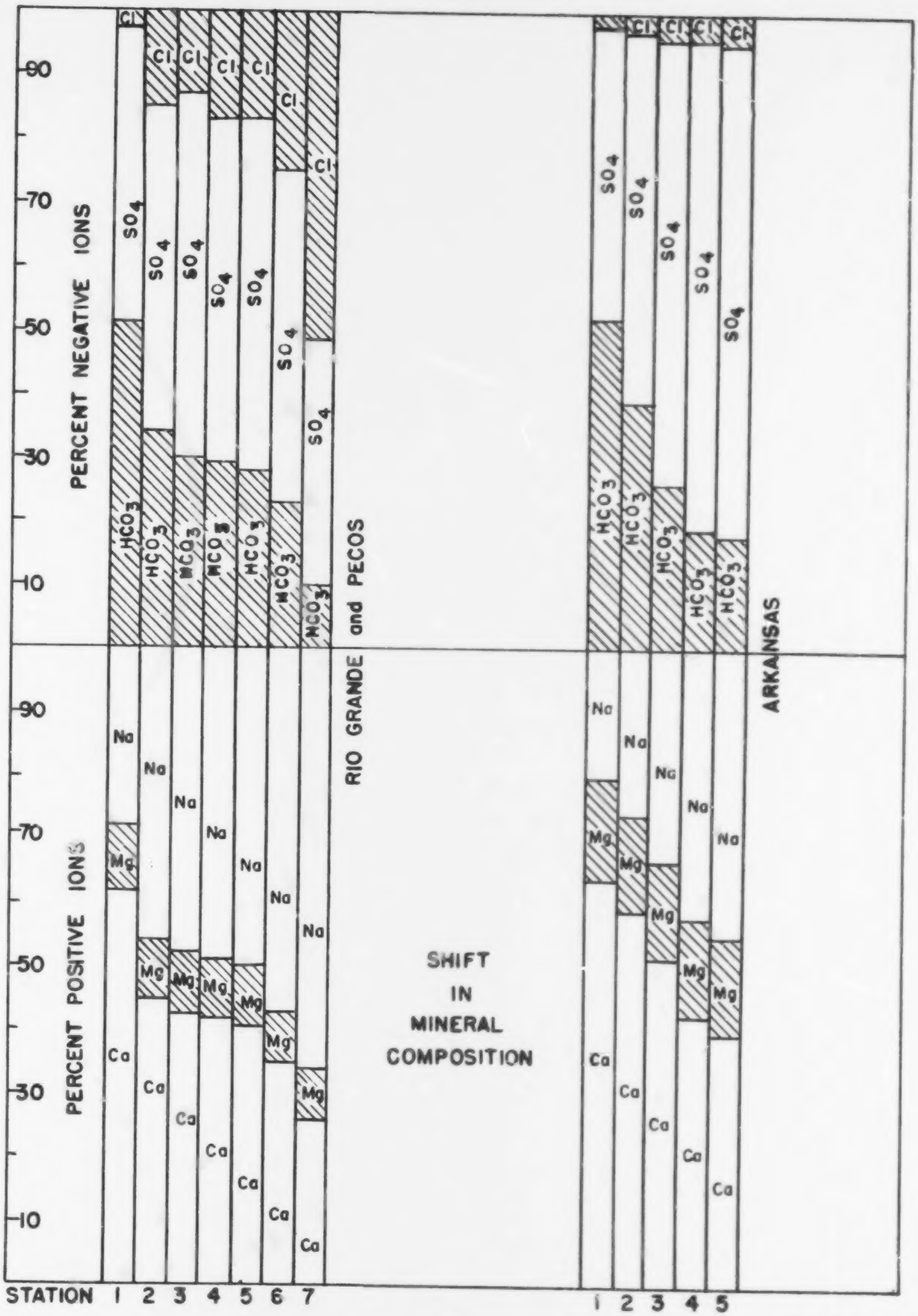

PERCENT NEGATIVE IONS
PERCENT POSITIVE IONS
10
30
50
70
90
Cl
SO4
HCO3
Na
Mg
Ca
RIO GRANDE and PECOS
ARKANSAS
SHIFT IN MINERAL COMPOSITION
STATION 1 2 3 4 5 6 7
1 2 3 4 5

FIGURE 11

entirely permanent hardness. Figure 11 shows a shift in percentage to sulfate and chloride downstream with a major shift to chloride at Station 7.

Significance of Salinity Changes

The water quality condition in the Rio Grande resulting from the use of water for irrigation is an example of stream pollution (63). The salt content of the water from Fort Quitman to below the confluence of the Pecos is too high to be safe for irrigation use. The salt content is diluted by tributaries in the lower river and is reused for irrigation at Roma and Brownville.

Water from much of the river, especially below El Paso (Station 47) to Roma is rendered unsatisfactory for domestic and industrial water supply due to the increase in salts. Because of the high sulfate and chloride content the water cannot be used for the production of steam and is unsatisfactory for most household and industrial uses unless treated by means of expensive ion-exchange methods. These elements also render the water unpalatable.

YAKIMA RIVER, WASHINGTON

Results of Surveys

The total irrigable area in the Yakima Valley is 621,000 acres of which more than 450,000 acres is actually under irrigation. Water from the Yakima River system is used for irrigation several times as it proceeds down the valley.

The water of the river originates in the Cascade mountains and is low in solids and of excellent quality. At no location is the salt content sufficiently high to interfere seriously with its reuse for irrigation.

The Washington Pollution Control Commission in 1951 made an intensive study of the river (64). The results obtained at eight sampling stations on the main stem are summarized in Table X and show the increase in salinity due to return flows. Most of the return flow enters the river below the Wapato diversion. The overall increase in salt content was more than 700 per cent. Total hardness increased from 33 ppm to 134 ppm as $CaCO_3$.

Washington State College in September and October 1927 made a survey of the Yakima Project (65). Most of these samples were collected in the area below the Wapato diversion.

The results showed that the solids content of the water applied as irrigation water (Sunnyside canal water) was less than 200 ppm and that of the return water varied from 400 to 600 ppm.

TABLE X

SALT CONTENT - YAKIMA RIVER (1951)

Sampling Station	Miles Travel	Dissolved Solids (ppm)	Remarks
Easton	0	41	
So. Cle Elum	17	49	Small diversions
Ellensburg	44	63	
Rosa Dam	71	51	Major diversion
Wapato Dam	92	74	Major diversion
Toppenish	108	326	Major return
Granger	115	348	Major return
Sunnyside	128	358	Major return

Seepage water was generally high in salt content but varied widely. Most of the seepage water samples contained from 500 to 5000 ppm dissolved salts. There were 90 samples in this classification. Eighteen contained salts in excess of 2000 ppm, 14 above 1000 ppm, and 57 between 500 and 1000. Sulfate and chloride content were high and were approximately equivalent to the alkaline-earth bases indicating a low carbonate concentration. Sodium was not determined as such.

Significance as Regards Water Use

While the salt content of the Yakima River during the study period increased about 700 per cent due primarily to return irrigation flows, the concentration was not sufficient to preclude the use of the water for domestic or industrial purposes. The hardness of 134 ppm was not objectionable for a domestic supply. Chlorides and sulfates did not reach proportions which would cause difficulties in industrial uses. However, a change in salt concentration of the magnitude indicated represents a deterioration even though the water may still be usable.

SUNNYSIDE (WASHINGTON) Valley Irrigation District

An investigation of the salt balance in the Sunnyside Valley Irrigation District (a part of the Yakima valley) was made by the Rubidoux Laboratory, Riverside, California, under an agreement with the Bureau of Reclamation and Bureau of Plant Industry. This investigation covered a 20 month period from October 1942 to July 1944. The purpose of the study was to determine the salt input and output.

The results are contained in unpublished reports by C. S. Scofield (66) and L. V. Wilcox (67). The irrigation water was measured and sampled at a station on the main canal about 2 miles north of Granger, Washington. Drainage water was sampled at 5 stations on the drainage system. Two of these stations represented the entire drainage output of the District. The area of land under irrigation in this District was 37,896 acres. The concentration of salts in ppm of the respective constituent is shown in Table XI.

The input of irrigation water for the two years was 167,931 and 164,060 acre-feet respectively. On the same basis the volume of return flow was 68,033 and 62,456 acre-feet respectively. The salt in input was 18,785 and 17,784 tons as against an output of 34,682 and 30,423 tons for the two years respectively. The volume of return flow in 1943 was 41 per cent of the applied water and in 1944, 38 per cent. The salt balance was considered favorable.

It is of interest to note that the nitrate content increased by several fold. Also of interest is the following quotation taken from one of the reports (67): "The fact that the output of nutrient

TABLE XI

INPUT AND OUTPUT SALT CONCENTRATION

SUNNYSIDE VALLEY IRRIGATION DISTRICT

Item		1943		1944	
		Input	Output	Input	Output
Water-acre feet		167,931	68,033	164,060	62,456
Dissolved salts-ppm		74	375	74	359
Ca	"	11	50	11	46
Mg	"	4	17	4	17
Na and K	"	6	54	7	51
HCO_3	"	60	111	63	109
SO_4	"	42	81	40	74
Cl	"	T	16	T	14
NO_3	"	1.2	10.3	T	7.5

constituents, potassium, nitrate and phosphate exceeds the input is not regarded as having any serious implication in respect to the sustained productivity of the soil of the District. The quantitities involved are small and an excess of output of these constituents is to be expected where the salt balance is favorable." This output of nutrients, however, is significant from the standpoint of aquatic growths in the streams below the project.

ARKANSAS RIVER

Upper River

Over 500,000 acres of land are under irrigation in that portion of the Arkansas River Basin located in Colorado (68). The return flow in the section between Pureblo and Holly, a distance of about 176 miles is in excess of 200,000 acre-feet per year (38) (69). Surveys made in this area starting about 1898 (70) show the increases in salinity due to the return flows.

Typical of these are the results of an investigation by the Bureau of Reclamation for the water year 1940-41 (38) (69). These results are shown in Table XII. The runoff pattern is characteristic of a stream that is utilized to its maximum for irrigation in that the flows decrease in spite of the influence of tributaries. Solids concentrations increased from 346 to 2034 ppm, about 600 per cent.

Table XII shows a shift in the proportional composition of the mineral ions similar to that experienced in the Rio Grande. The proportion of sodium increased substantially, while that of calcium decreased. Magnesium remained fairly constant. The proportion of sulfate and chloride ions increased, while bicarbonate decreased. However, the chloride did not increase in the same proportion as was indicated in the Rio Grande. Sulfate content of the water at the last station was 76 per cen[illegible]f the total negative ion concentration, while the chloride was only 6 per cent. At the last station on the Rio Grande the sulfate was 39 per cent and the chloride 51 per cent.

Lower River

The U. S. Geological Survey, as part of its network of stations, has established eight stations on the Arkansas and its tributaries, the Cimarron and Canadian. An analysis was made of the results obtained at these stations during the period 1951 through 1954 (23) (24) (25) (38). The data do not show a progressive increase in solids concentration proceeding downstream, undoubtedly due to dilution by large volumes of water from tributaries as compared to the quantity of return flows. Water leaving the Colorado stretch of the river contained dissolved solids in weighted average concentrations between 1500 and 1700 ppm. These were reduced to 500 and 900 at the lower sampling point located at the Oklahoma-Arkansas border.

TABLE XII

SALT CONTENT ARKANSAS RIVER

Water Year 1940-41

Station No.*	Runoff 1000 acre ft.	Dissolved Solids		Ca	Mg	Na	HCO_3	SO_4	Cl	NO_3
		ppm	1000 tons	ppm	ppm	ppm	ppm	ppm	ppm	ppm
1	503	346	237	59	15	18	137	122	7	2.5
2	568	542	419	92	24	40	165	249	12	4.3
3	108	1088	160	154	45	99	207	555	27	2.5
4	310	1376	580	170	61	158	195	775	36	1.8
5	169	2034	468	217	83	241	243	1050	81	4.3

*Station 1 - Pueblo
2 - Nepasta
3 - La Junta
4 - Caddoa
5 - Holly

SUTTER BASIN, CALIFORNIA

The U. S. Regional Salinity and Rubidoux Laboratory, in cooperation with the Sutter Mutual Water Company, conducted salt balance studies in the Reclamation District No. 1500 in Sutter County, California, during two periods, 1931 through 1933, and 1946 and 1947. The results of the 1946 and 1947 studies are contained in unpublished reports of the laboratory (71) (72). These reports contain data from the 1931 - 33 survey for comparison with those of the later study.

The acreage under irrigation was 45,028 acres. The input of water during 1947 was 299,300 acre-feet and the output 152,110 acre-feet. On an acre basis the input was 6.65 acre-feet; return flow 3.38 acre-feet; and consumptive use 3.27 acre-feet. During 1946 the latter was 3.46 acre-feet.

The composition of the irrigation input and drainage output for each of the years of the five-year period are shown in Table XIII. Total dissolved salts in the drainage water were approximately 5 times greater than in the irrigation supply in 1947 and 6 times in 1946. The increase in salts during this period was substantially less than that of the three years of the earlier period (7, 10 and 7 times respectively for 1931, '32, and '33). According to the reports of the laboratory (72) this was probably due to salts from a "very saline ground water that underlies the area" and which may have been gradually removed by leaching.

Sodium increased as expected, however, the considerable increase in magnesium is noteworthy. In other areas, such as the Rio Grande and Arkansas (see Figure 11), magnesium content remained rather constant even with substantial increases in calcium. Other differences apparent from a study of the data are:

1. A greater than usual increase in bicarbonate. In other waters studied the bicarbonate content did not increase substantially. In this case the bicarbonate content of the drainage water was over 300 per cent of that of the irrigation supply.

2. The sulfate content of both irrigation water and drainage was much lower than would be expected from the results of irrigation in other areas.

3. The chloride content increased by a much greater percentage than any of the other ions.

From these data it is apparent that chlorides of calcium, magnesium and sodium were present in the soils or shallow ground water of this region and that they have been gradually leached into the drainage water. The laboratory's report indicates that these salts may come from the artesian ground-water aquifer and that there was

TABLE XIII

INPUT AND OUTPUT OF MINERAL SALTS

SUTTER BASIN, CALIFORNIA

Year		Salts ppm	Ca ppm	Mg ppm	Na ppm	HCO_3 ppm	SO_4 ppm	Cl ppm	NO_3 ppm
1931	Input	140	17	10	11	107	8	9	0.12
	Output	1008	77	59	150	268	30	364	0.06
1932	Input	125	15	10	12	97	5	6	0.12
	Output	1294	96	78	193	283	36	518	0.06
1933	Input	140	15	8	16	100	6	11	0.31
	Output	950	67	57	152	276	31	335	0.50
1946	Input	103	12	6	9	75	7	5	0.31
	Output	603	52	41	105	277	36	184	0.62
1947	Input	125	14	8	13	88	11	9	T
	Output	611	52	40	102	255	25	197	0.25

less contamination from this source during the latter period.

This study indicates the variations which are possible in return irrigation flows in different regions of the country. These variations have many causes which are related to the specific conditions existing in the region.

UPPER COLORADO RIVER BASIN

Return irrigation flows are, of course, but one of several factors affecting the salinity of a flowing stream. A natural stream increases in salt content as it flows downstream toward its mouth, as is illustrated by the results of analyses reported for six stations (73) over much of the main stem of the Colorado River from Hot Sulfur Springs, Colorado, to the main Yuma canal. Dissolved salts increased from 64 ppm to 699 ppm, or almost 11 times. The major increases were in sodium, 6 to 104 ppm (17 times), sulfate, 3.5 to 300 ppm (85 times) and chloride, 2 to 82 ppm (41 times).

The report (73) gives the causes for the increase in salinity as natural inflow of ground water and the return wastes from industry and agriculture. The stretch of the river near Grand Junction is used extensively for irrigation. This area is served by the Grand Valley Diversion Dam near Cameo, Colorado. The increase in salinity between this diversion and the main river at Grand Junction (about 25 miles) is shown in Table XIV. This table (73) also shows the salt content of a drain carrying return flow from this project. Of interest in the data in Table XIV is the decrease in chloride ion and large increase in magnesium.

TABLE XIV

Salinity Increase, Grand Valley Project, Colorado

Location	Dissolved Solids ppm	Ca ppm	Mg ppm	Na ppm	HCO_3 ppm	SO_4 ppm	Cl ppm
1*	1151	118	31	244	239	270	348
2*	1553	145	66	290	256	565	320
3*	6400	522	434	855	388	4054	241

*No. 1 - Colorado at Cameo above Grand Valley diversion.
No. 2 - Colorado at Grand Junction.
No. 3 - Drain in Grand Valley Project near Loma.

The mean annual discharge of the Colorado between 1925 and 1930 was 15,700,00 acre-feet. This water carried over 12 million tons of salts most of which was contributed by drainage of irrigated land in the upper basin.

Scofield (63) states that future diversions in the upper basin will decrease flow, but not the salt burden. When the Colorado program has been completed, stream flow will be reduced to 8 to 10 million acre-feet passing through Grand Canyon. This water will carry at least the same burden of salt as contained in the 16 million acre-feet of 1932. Users for irrigation in the lower valley must use water with twice the salt concentration and therefore will be required to use more water for proper drainage to maintain a favorable salt balance. Even in 1932 an adverse salt balance was indicated for the Imperial Valley. In 1930 - 32 the input was 3 million tons and the output slightly less than 2 million.

Table XV contains the means of salinity data for 1947 to 1955 collected by the U. S. Geological Survey (74) on the upper Colorado River. Figure 12 shows the location of these sampling stations. The 23 stations are located on the main stem and principal tributaries from Hot Springs, Colorado, to Lees Ferry, Arizona. From these data it is possible to observe the factors which influence water quality at the various sampling stations, but the papers do not contain specific data relative to the quality of return irrigation flows. This quality, as in most reports, is implied in the analysis of the river samples and is not separated from other influencing factors.

COLUMBIA BASIN PROJECT

The Columbia Basin irrigation project is comparatively new. At the present time approximately half of the potential one million acres has been authorized for development by the Bureau of Reclamation. Much of the authorized area is under irrigation, but has largely been developed during the past few years.

Water is pumped from the Columbia into artificial reservoirs from which it flows to two main canals serving the upper portion of the project. Most of the return flow and excess water from the upper area is collected in Potholes Reservoir from which canals serve the lower area. Thus, the area is self-contained so far as the use of water is concerned. Rainfall is very limited, especially in the summer.

In the initial stages of the development of the areas much of the drainage water was retained in the ground water. Ground water elevations have risen in the developed areas and in some cases ground water is presently overflowing into surface drains. It is expected that eventually equilibrium will be reached over the entire project, and essentially all drainage water will enter surface waters.

Several surveys have been made in the area to determine the extent of the salinity increase resulting from irrigation return flows. One of

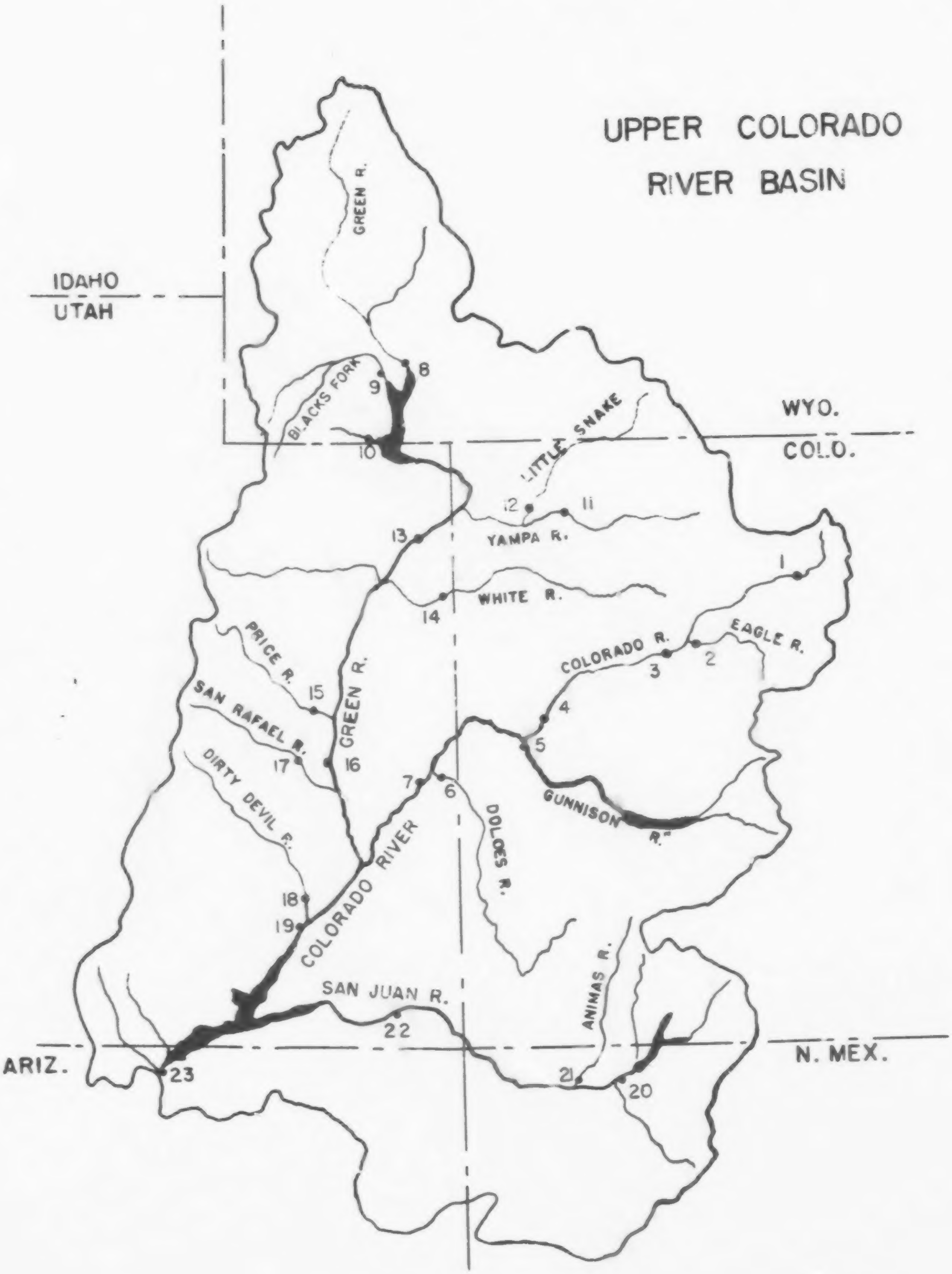

UPPER COLORADO
RIVER BASIN
IDAHO
UTAH
WYO.
COLO.
ARIZ.
N. MEX.
GREEN R.
BLACKS FORK
LITTLE SNAKE
YAMPA R.
WHITE R.
COLORADO R.
EAGLE R.
PRICE R.
SAN RAFAEL R.
GREEN R.
DIRTY DEVIL R.
GUNNISON R.
DOLOES R.
COLORADO RIVER
SAN JUAN R.
ANIMAS R.
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FIGURE 12

TABLE XV

SALINITY DATA, UPPER COLORADO RIVER BASIN
(Water Years 1946-1955)

Sampling Station *	Irrigated area above station 1000 acres	Mean annual discharge 1000 acre-feet	Mean dissolved solids ppm	Mean hardness as $CaCO_3$ ppm	Mean sulfate ppm
1	13	271	78	47	6
2	15	427	511	311	195
3	70	1707	391	183	87
4	160	2859	590	250	142
5	238	1586	1042	559	574
6	36	486	1672	454	323
7	530	4843	993	454	411
8	150	1128	398	238	170
9	74	238	1105	506	624
10	21	49	1118	708	574
11	65	907	248	142	62
12	21	341	466	200	160
13	331	3803	432	254	178
14	30	473	552	286	175
15	18	129	3682	1431	2398
16	551	4392	635	310	215
17	36	105	2987	1305	1863
18	15		2182	1212	1193
19	1149	8952	851	435	387
20	52	732	238	137	75
21	30	562	466	278	189
22	190	1422	652	348	354
23	1342	11126	802	418	380

*Sampling stations
1. Colorado at Hot Sulphur Springs
2. Eagle at Gypsum
3. Colorado at Glenwood Springs
4. Colorado at Cameo
5. Gunnison near Grand Junction
6. Dolores near Cisco
7. Colorado near Cisco
8. Green near Green River, Wyoming
9. Blasks Fork near Green River
10. Henry's Fork at Linwood
11. Yampa near Maybell
12. Little Snake near Lily
13. Green at Jensen
14. White near Watson
15. Price at Woodside
16. Green at Green River, Utah
17. San Rafael near Green River
18. Dirty Devil near Hite
19. Colorado at Hite
20. San Juan near Blance
21. Animas at Farmington
22. San Juan near Bluff
23. Colorado at Lees Ferry

these was conducted during 1954 and 1955 (26) (27). The second consists of a continuing series of samplings conducted by the Bureau of Reclamation. The data from five of these series were reported in unofficial tabulations during the period 1956 and 1957. The study covers nine surface and six well water samples. The locations of the surface water samples are shown in Figure 13. The averages of the five series are shown in Table XVI. The increase in salinity caused by return flow is not as yet significant, since the area is not completely developed and large amounts of water of low salinity are available.

Sampling stations 1 and 10 (Table XVI) represent respectively the water in and out of the project. The major increases in salt content involve sodium, magnesium, sulfate and chloride. Calcium remained almost constant. The increase in magnesium is to be expected in the low concentration involved since magnesium carbonate is approximately ten times more soluble in cold water than calcium carbonate.

Table XVI shows the salt content of the six wells from which samples were collected. The ground water contains considerably more salt than the surface water. The portion of this salt which may be due to irrigation drainage cannot be determined from the available data, since there is no history of the salt content of the well water involved.

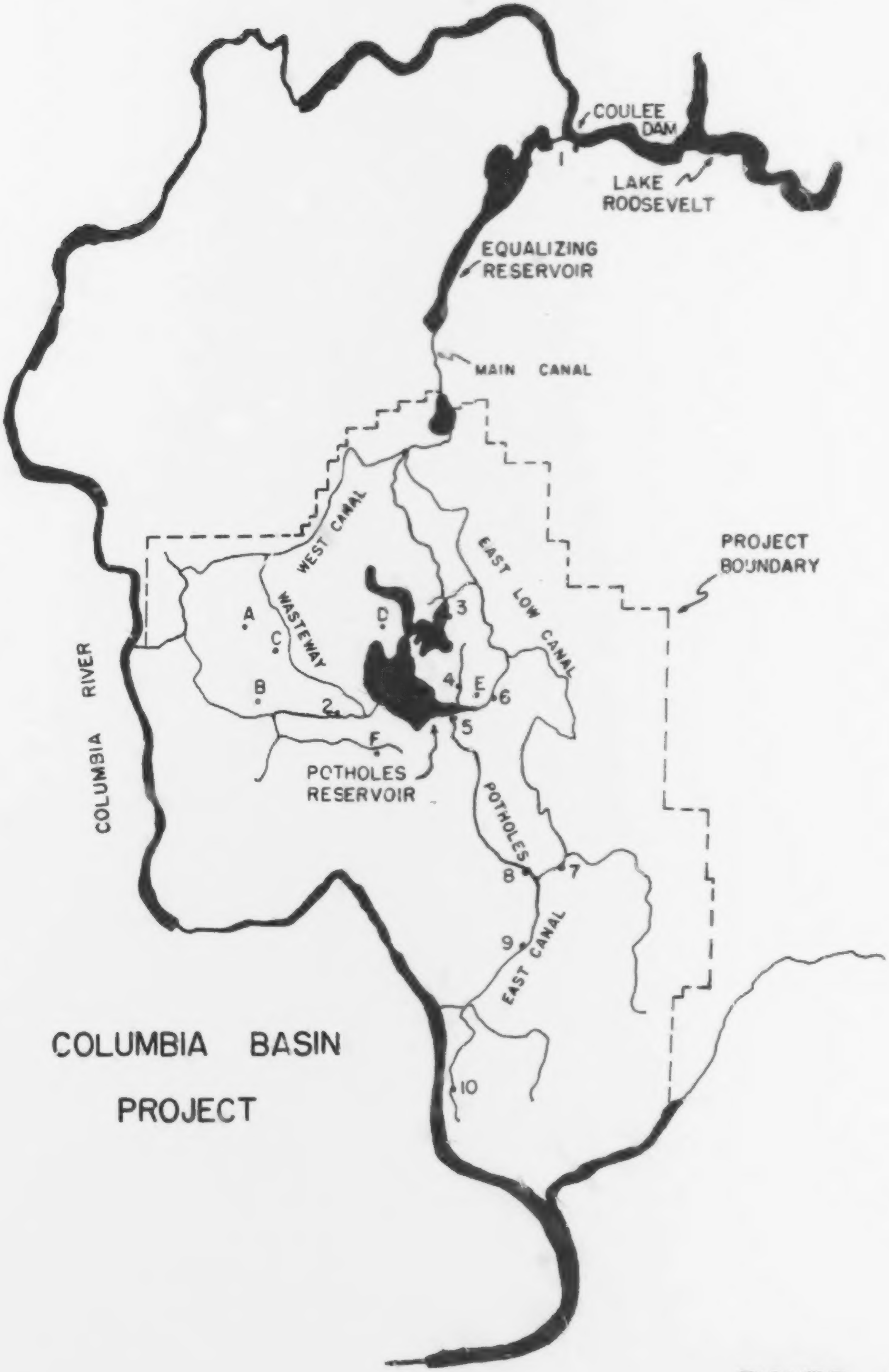
BOISE RIVER, IDAHO

A series of samples collected during 1948 and 1949 in the Boise River Basin, (Idaho) (75), indicate the magnitude of salt pickup due to irrigation in that area. The increase is demonstrated by the results obtained at two stations (Table XVII). The first was located at Diversion which represents the water applied. The second was from the return flow in Notus Canal. The concentration of salts increased by almost 8 times, the greatest involving sodium, sulfate and chloride. Other areas covered by the report of this study show similar return flow quality patterns.

The University of Idaho, in cooperation with the Bureau of Reclamation, have completed a project to determine the quality of ground water in the Boise Valley (76). A large number of samples were collected from a total of 60 stations, mostly existing wells. These sources of water were classified according to their value for irrigation. However, since there was no historical background indicated, the results do not indicate the effect of irrigation drainage on ground water quality.

SAN JOAQUIN AND SACRAMENTO

The California Department of Water Resources in 1951 initiated a survey of the quality of surface waters in California. A total of 150 stations were selected on 90 major streams of the State. Seventy-nine of these were located in the central valley which drains from the north to the Sacramento River and from the south to the San Joaquin River. Nine stations were located on each of the main stems of these two rivers.


COULEE DAM
LAKE ROOSEVELT
EQUALIZING RESERVOIR
MAIN CANAL
PROJECT BOUNDARY
WEST CANAL
EAST LOW CANAL
WASTEWAY
A
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COLUMBIA RIVER
POTHOLES RESERVOIR
POTHOLES
EAST CANAL
COLUMBIA BASIN
PROJECT

FIGURE 13

TABLE XVI

SALINITY OF WATER IN THE COLUMBIA BASIN PROJECT

Sampling Station	EC 25°C	Ca ppm	Mg ppm	Na ppm	HCO_3 ppm	SO_4 ppm	Cl ppm	NO_3 ppm
1. Lake Roosevelt	150	21	5	2	76	12	1	0.8
2. Frenchman Wasteway	213	22	8	10	91	20	4	0.5
3. Moses Lake	396	28	15	33	182	33	11	2.0
4. Wasteway	204	25	8	8	101	19	4	2.0
5. Potholes E. Canal Mile 0	345	24	13	28	163	27	10	1.1
6. Lind Coulee	301	32	10	15	113	37	12	2.5
7. Scooteney Wasteway	159	21	6	4	82	13	1	0.7
8. Potholes E. Canal Mile 26	335	24	13	26	159	24	11	0.5
9. Potholes E. Canal Mile 38	321	24	12	24	154	25	10	0.2
10. Potholes E. Canal Mile 66	318	24	12	24	146	26	10	0.5
A. Well*	834	92	46	20	201	214	12	68.0
B. Well	653	44	44	37	299	203	12	1.8
C. Well	431	38	16	26	201	52	10	3.1
D. Well	955	58	45	86	530	63	24	13.6
E. Well	495	40	25	25	173	34	16	69.0
F. Well	517	31	37	29	263	51	3	20.0

*See location on Figure 13

TABLE XVII

SALT PICKUP, BOISE RIVER BASIN, IDAHO

Test	River at Diversion	Return flow at Notus Canal	Percent Increase
Dissolved salts ppm	60	456	778
E.C. at 25°C, x 10^3	0.10	0.76	---
Ca	11	58	527
Mg	3	18	600
Na	5	86	1720
HCO^3	49	252	515
SO_4	8	144	1800
Cl	5	40	800

(See Figure 14). A major portion of the irrigated areas of California lies in the lower central valley (San Joaquin).

The results of the surveys for 1951 through 1956 are reported in two bulletins (77) and (78). A series of tests made during September of 1956 are typical of the water quality on the main stems of the rivers at this season which is representative of the dry period when irrigation has about reached its peak (Table XVIII and Figure 14).

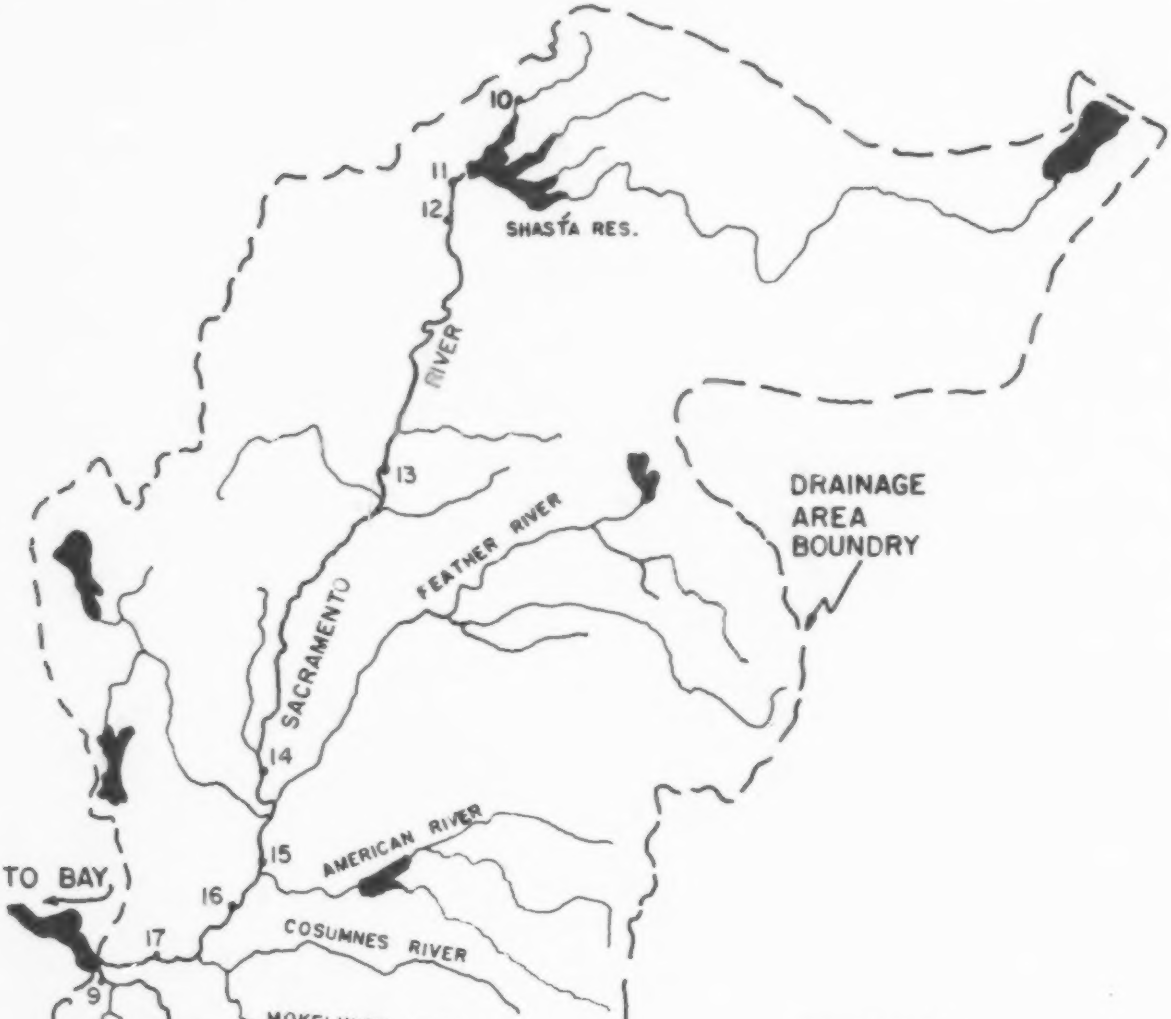
The marked difference between salt content of the water of the two rivers is shown in Table XVIII. Some of this difference can be accounted for by dilution from more abundant rainfall and runoff in the northern area, as well as a more complete "leaching of the alluvium in past geological time" (78, page 20). A major source of salts in the San Joaquin River water, however, is return irrigation flows. The effect is most apparent in periods of low flow when sodium is high in comparison to other cations, and sulfate and chloride are greater than bicarbonate.

The above referred to reports state that the San Joaquin shows a continuing trend toward greater mineralization. It is expected that this trend "will continue until imported waters are available to provide sufficient dilution to carry off the increasing amounts of return irrigation flows---."

The increasingly poor quality of water available in the lower San Joaquin Valley and the concern caused by this trend have led to an investigation of water quality in that area. This investigation resulted in an Interim Report prepared by the Department of Water Resources (25). The following statement pertinent to a consideration of return flows is taken from this report: "As a result of the development of lands within a potentially productive agricultural basin, return flows generally increase as the quantity of applied water increases. Such return flows comprising irrigation water, effluent ground water and ground water pumped for water table control, may be either beneficial or detrimental as illustrated by conditions in the lower San Joaquin River. Due to an increase in concentration of mineral constituents by various factors, such as consumptive use and leaching, return flows tend to degrade better quality waters with which they are mixed. On the other hand, return flows in which mineral constituents are not excessive supplement and often times supply waters required by downstream users."

Data in this report (25) shows the high magnesium content of some surface and ground waters. This magnesium content is said to be related to the type of rocks in the drainage areas involved, due to high percentages of ferro-magnesium minerals in these rocks.

Figure 15 was taken from the report (25, Plate 7) and shows the average dissolved solids concentration for the periods 1938 to 1950, and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11
12
SHASTA RES.
RIVER
13
DRAINAGE
AREA
BOUNDRY
FEATHER RIVER
SACRAMENTO
14
15
AMERICAN RIVER
TO BAY
16
17
COSUMNES RIVER
9
MOKELUMNE RIVER
8
RIVER
7
6
STANISLEUS RIVER
5
TUOLUMNE RIVER
4
MERCED
RIVER
SAN JOAQUIN
3
FRESNO RIVER
2
1

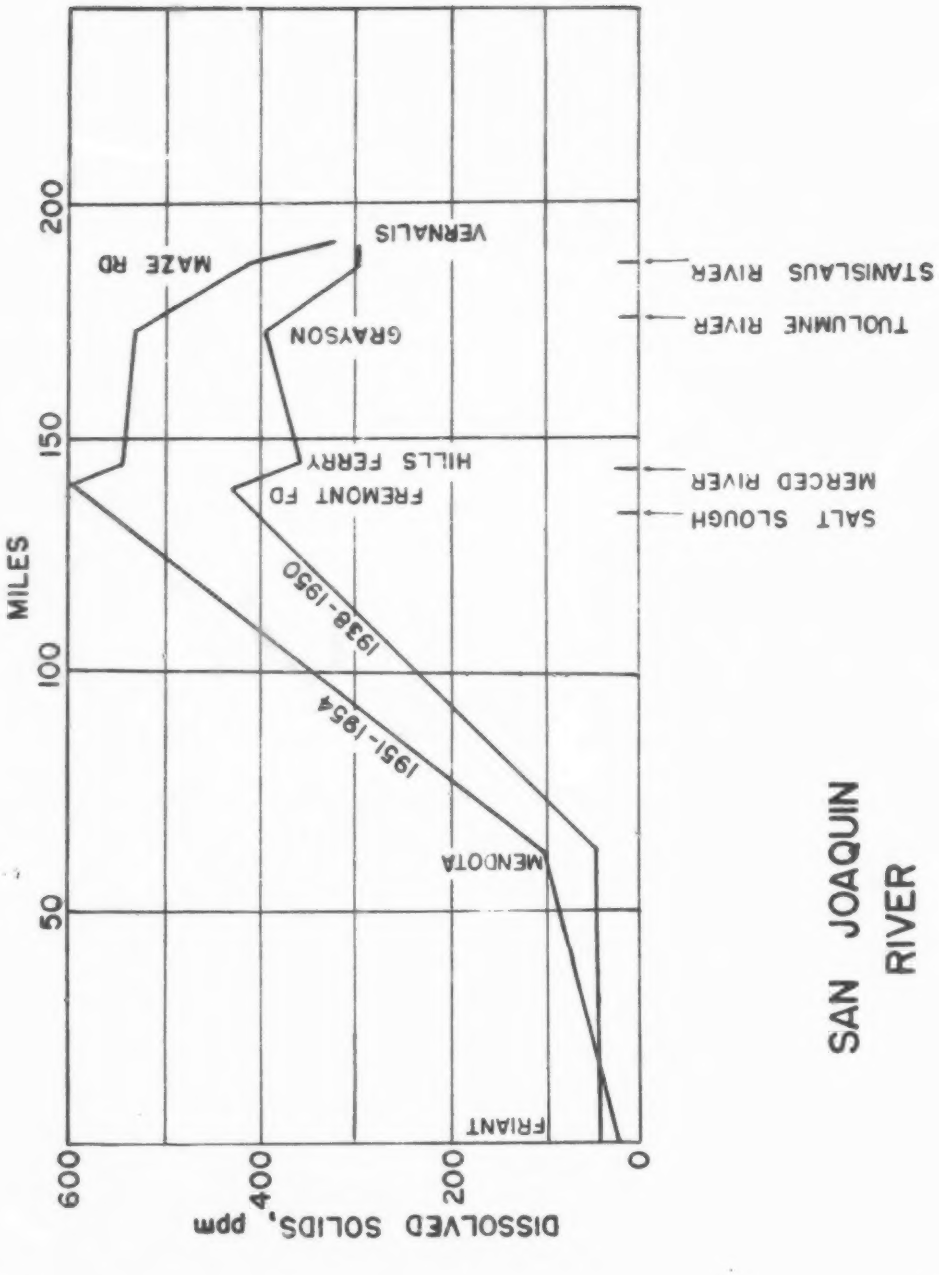
CENTRAL
VALLEY
CALIFORNIA

FIGURE 14

TABLE XVIII

QUALITY OF SAN JOAQUIN AND SACRAMENTO RIVERS

Sampling Station	Dissolved solids ppm	Ca ppm	Mg ppm	Na ppm	HCO_3 ppm	SO_4 ppm	Cl ppm
San Joaquin							
1. At Friant	27	2	1	2	16	2	T
2. At Mendota	304	29	13	57	112	46	84
3. At Dos Palos	314	31	12	61	115	47	85
4. At Grayson	469	41	18	99	162	82	122
5. Maze Road	312	30	11	64	112	36	91
6. At Vernalis	299	30	11	57	119	32	81
7. Mossdale Br.	327	32	13	64	128	34	92
8. Garwood Br.	315	31	12	63	126	35	88
9. At Antioch	381	18	16	96	85	32	158
Sacramento							
10. At Delta	118	9	7	11	80	2	6
11. At Keswick	73	10	3	5	57	3	T
12. At Redding	72	10	3	5	56	4	T
13. Hamilton City	78	10	5	5	63	3	1
14. Knights Landing	125	14	8	14	95	12	6
15. Sacramento	82	10	5	9	62	6	5
16. Snodgrass Slough	143	16	9	18	103	12	14
17. Rio Vista	129	15	8	15	98	13	9



SAN JOAQUIN
RIVER

FIGURE 15

and 1951 to 1954. Much of the increase in salt from Mendota to Fremont Ford is due to return flows. Water of better quality from tributaries below Fremont Ford serves to somewhat reduce the concentration in the lower river.

SACRAMENTO - SAN JOAQUIN DELTA

The California Department of Water Resources during the period from May 1954 through October 1955 made a detailed water quantity and quality survey of water applied to and drained from the Sacramento - San Joaquin Delta lowlands (79). The Delta consists of about 469,000 acres of land, 374,000 of which are farm lands. These lands are at or below sea-level and are protected by dikes. The area is interlaced by 600 miles of canals. During the period of the survey about 292,000 acres of this area were irrigated using surplus water from the Sacramento Valley.

The purposes of the survey were to determine the quantitites of water applied to the irrigated crops and the "extent and sources of degradation in quality of the channel waters from the Sacramento River to the Tracy Pumping Station." These two points represent the inflow and outflow of the Delta respectively.

Surface soils are of two types, sedimentary mineral ranging from loamy sand to clay and organic ranging from mucky loam to peat. The area was divided into three parts on the basis of soil types; namely, the north mineral, middle organic, and south mineral. There are six major irrigated crops raised on Delta lowlands. Methods of irrigation vary from furrow type to sprinkler. Most irrigation is in late spring and summer. Due to an increase in salinity in the channel waters, some farmers cease irrigation in late summer to prevent damage to crops.

Salinity increases in the soil during the irrigation season. The salts are removed in the fall when ample water is available by applying excess water to the irrigated land. (An item of interest is the quantity of water applied for various crops. These data are given in Table XIX as a matter of record).

Drainage water is collected in lateral drains and pumped to the main canals. There are 206 pumping plants involving 319 pumps used to transfer drainage water to the canals. This drainage water was measured and analyzed as was the water applied. The total quantity of water applied in the area was 656,000 acre-feet per season or an average of 2.25 acre-feet per acre. The results of measurements and analyses made during March through October 1955 are shown in Table XX.

The analysis of the salt contribution by irrigation return flows in this area is complicated by possible sea-water intrusion, seepage

TABLE XIX

QUANTITY OF WATER APPLIED TO CROPS

SACRAMENTO-SAN JOAQUIN DELTA

	Weighted mean depth in inches		
Crop	North mineral	Middle organic	South mineral
Field corn	17.6	43.3	17.6
Alfalfa	28.2	----	50.4
Sugar Beets	22.6	39.0	45.0
Tomatoes	29.4	40.9	31.0
Pasture	25.9	----	99.7
Asparagus	----	16.6	7.9

TABLE XX

WATER APPLIED TO AND DRAINED FROM SACRAMENTO-SAN JOAQUIN DELTA

	Applied Water		Drainage Water	
1955	Quantity Acre-ft.	Salt concentration ppm	Quantity Acre-ft	Salt concentration ppm
March	6,560	237	32,419	723
April	26,240	205	37,628	673
May	45,910	183	49,813	437
June	118,060	158	71,084	373
July	216,450	198	80,606	331
August	170,540	246	72,170	335
September	65,590	262	43,116	440
October	6,560	245	30,017	475

from canals to drainage collection ditches and by rising water from deep strata. However, the conclusion drawn from the study is: "The Delta Lowlands act as a salt reservoir storing salts obtained largely from the canals during the summer, when water quality in such canals is most critical and returning such accumulated salts to canals during the winter when water quality is least important. The highest concentration of salts (85.5 ppm) in drainage water occurred in January, 1955. This conclusion is based on irrigation use since concentrations of salts may affect other uses during the winter as well as other period of the year."

APPENDIX B

89.A

APPENDIX B

TEMPERATURE

YAKIMA RIVER BASIN, WASHINGTON

As a part of a survey of the Yakima River in 1955 by the Washington Pollution Control Commission, thermographs were installed at three stations to record the air and water temperatures. The objective was to obtain information regarding the effects of irrigation and return irrigation flows on the temperature characteristics of the water of the stream. These data are unpublished but have been made available for this report.

Station Locations

The location of the three stations are shown on Figure 16. The first, "Station No. 1" was located at Donald-Wapato Bridge (River mile 80) which is below major irrigation diversions and above points of return flow. A flow recorder is located in the river near this station (at Parker).

Station No. 2 was located at the "Chandler power drop" (River mile 30) about 50 miles below No. 1. This station is below the major return flows, and any influence of return flows on the temperature of the river should be reflected by the recordings at this station. A flow gaging station is located at Kiona about 5 miles below No. 2. The flow time between stations 1 and 2 is approximately 35 hours.

Station No. 3 was located about 1/2 mile above the mouth of the river where it enters the Columbia and 30 miles below No. 2. Only a comparatively small amount of water is diverted from the river between the lower two stations and only a limited amount of return flow enters the river in this section. The flow time between stations 2 and 3 is approximately 9 hours.

Period of Data Collection

Temperature data was collected for the period of July until the middle of October. However, for the purpose of this analysis, that collected during August and September will be used, since irrigation was at its maximum during this period. The year 1955 was an average flow year. Water temperatures, therefore, may not be representative of the maximum possible during periods of low flow. However, this is a factor of magnitude and is not an influencing factor in this analysis, although it may have serious implications in the Yakima Basin during those periods when larger proportions of the river flow are diverted.

YAKIMA RIVER
TEMPERATURE STATIONS

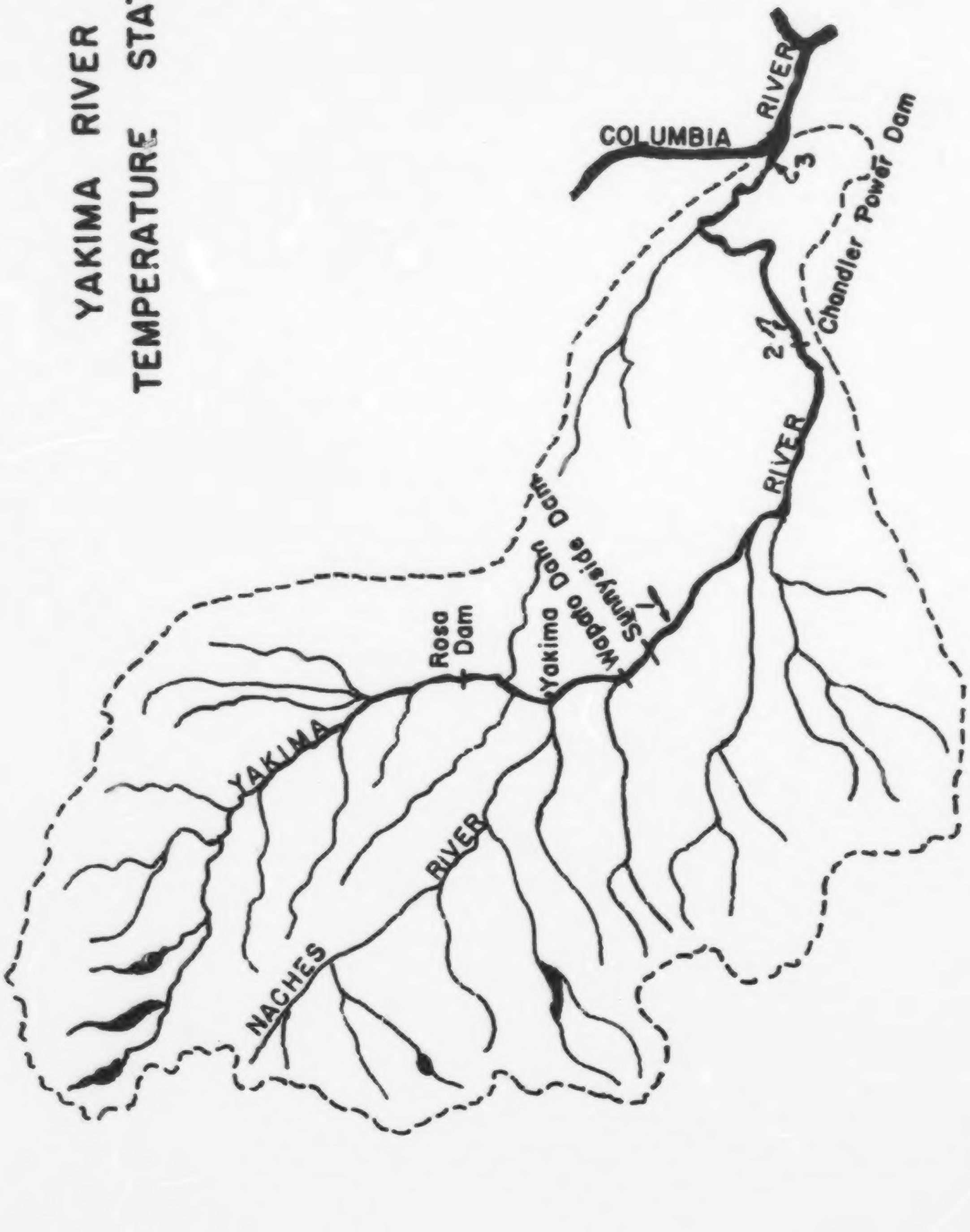

COLUMBIA
RIVER
3
Chandler Power Dam
2
RIVER
Sunnyside Dam
Wapato Dam
Yakima
1
Rosa Dam
YAKIMA
RIVER
NACHES

Figure 16

Diversions

Three major diversions are located in the river above the first stations: Rosa diversion about 10 miles above the City of Yakima; Wapato diversion five miles below Yakima and about five miles above station No. 1; and the Sunnyside diversion, two and one-half miles above station 1.

Table XXI indicates the magnitude of the diversions at each of these dams during the two-months period (August and September, 1955).

TABLE XXI

Magnitude of Diversion (cfs)

Date	Rosa	Wapato	Sunnyside
August 5	939	1775	1270
August 18	1006	1640	1280
September 1	954	1525	1195
September 15	704	1470	1045
September 29	544	1315	860

Return Flow, Quantity

The flow of the Yakima is gaged by stations at Parker and Kiona. The gaging at Parker is representative of the flow at station No. 1. That at Kiona is sufficiently representative of the flow at station No. 1 for the purpose of this analysis. There is a lag of about 1 1/2 days between the flows at these two stations. The difference between the flows, corrected for this lag, represents the flow of return irrigation water. The average for August was 1250 cfs and for September 1650 cfs. Using the diversion flows from Table XXI as roughly representative of the average diversion for each of the two months, estimates of the percentage return were made as follows:

August:	
Average combined diversions	3955 cfs
Average return flow	1250 cfs
Per cent return	31.7
September:	
Average combined diversions	3204 cfs
Average return flow	1650 cfs
Per cent return	51.5
Two-months Period:	
Average combined diversions	3504 cfs
Average return flow	1447 cfs
Per cent return	41.3

August data are considered to be typical for this area. Decreased temperatures near the end of September resulted in a decrease in the water applied to the land and a subsequent increase in overflow. This accounts for the higher percentage return.

Air and Water Temperatures

Tables 22,23, and 24 give the maximum, minimum and average temperatures of both air and water at stations 1, 2, and 3 respectively for the two-months (August and September, 1955).

Maximum water temperatures at the three stations are plotted in Figures 17. This plot indicates the effect of irrigation and irrigation return flows on the water temperature of the river. The water temperatures at station 2 were 9 to 19°F above those at station 1. This is the area of major return flows. There is only a slight increase in water temperature between stations 2 and 3. The difference in flow time of the river in each case does not account for the wide variation in the increase in temperatures at these stations. The average increase in water temperature between stations 1 and 2 is about 14°F and between stations 2 and 3, about 1.5°F.

It is not possible from the data collected to determine definitely whether the major increase occurred in the canals or ditches or as a result of the application of the water to the land. It is clear, however that there was a definite correlation between air and water temperatures. This is to be expected, of course, since the conditions causing increases or decreases in temperatures of water and air are the same. (Figure 18 shows the maximum air and water temperatures at the Chandler station, No. 2).

Figure 18 shows the return flows in cfs at station 2. Since there is no correlation between the temperatures and the quality of return flow, it can be assumed that at least a significant part of the increase in the temperature of the water diverted for irrigation occurs in the canals and ditches.

Figure 18 also shows the effect of a decrease in temperature on the volume of return flow. This is due to several factors among which are: a decrease in application, since less water is needed; lower losses due to transpiration and evaporation; and greater overflows.

Conclusion

Irrigation and return irrigation flows appear to have a significant effect on the temperature of the water of the Yakima River.

From the data presented here, it can be concluded that similar effects occur in other reclamation areas.

The increase in water temperature is directly correlated with the air temperature. It should, therefore, be possible to predict (roughly at least) the possible effects of irrigation on water temperatures. This is an area for further study with a good chance of arriving at a usable method.

TABLE XXII

STATION NO. 1

Donald-Wapato Bridge
Water and Air Temperatures in Degrees of Fahrenheit

	August						September					
	Water Temp.			Air Temp.			Water Temp.			Air Temp.		
Date	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Ave.
1	65	57	61	84	61	73	56	48	52	88*	53	71
2	62	56	59	79	60	70	57	50	53	89	55	72
3	61	53	57	80	56	68	58	51	54	92	62	77
4	62	53	57	86	54	69	58	51	54	91	58	75
5	64	55	59	90	55	72	57	50	53	91	56	73
6	64	56	60	95	57	76	57	50	53	91	58	74
7	64	56	60	92	62	77	55	51	53	87	71	79
8	62	55	58	85*	55	70	54	49	51	76	63	70
9	62	53	57	85	55	70	55	48	52	82	53	67
10	63	53	58	90	55	72	56	48	52	84	53	68
11	62	55	58	87*	69	78	55	47	51	82	59	71
12	62	53	58	81	62	71	53	46	49	78*	47*	63
13	58	51	54	81	55	68	48	47	48	65	50*	57
14	59	51	55	84*	55	70	47	45	46	65	50	57
15	59	51	55	87*	61	74	47	43	45	64	46	50
16	59	52	55	85*	62	74	48	43	46	67	46	56
17	60	52	55	86	59	68	48	42	45	70	46	58
18	60	52	56	87*	59	74	49	43	45	76	51	64
19	61	53	56	88	68	78	50	44	47	80	46	63
20	60	53	56	82	60	71	50	45	47	67	47	57
21	58	50	54	81*	51	68	46	42	44	64	47	56
22	59	51	55	83*	60	72	45	40	43	65	37	51
23	58	50	54	81	59	70	48	41	44	72	46	59
24	57	49	52	80	57	69	48	43	45	71	43	57
25	56	48	52	77	53	65	47	41	44	73	40	56
26	56	48	53	78	55	67	46	41	43	70	38	54
27	57	48	52	83	53	68	44	43	44	58	55	56
28	57	49	53	81	60	71	45	41	43	64	45	60
29	57	49	53	88	53	70	45	39	42	68	39	53
30	57	50	53	89	59	74	45	39	42	69	41	55
31	57	49	53	86	54	70						

TABLE XXIII

STATION NO. 2

Chandler
Water and Air Temperatures in Degrees of Fahrenheit

	August						September					
	Water Temp.			Air Temp.			Water Temp.			Air Temp.		
Date	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
1	74	67	70	88	60	74	73	63	68	96	46	71
2	74	66	70	86	48	67	72	64	68	97	48	73
3	73	65	69	84	45	65	72	65	69	94	54	74
4	73	64	69	87	46	67	72	65	68	92	68	80
5	75	64	69	96	50	73	72	65	69	94	52	73
6	76	66	71	99	52	76	71	56	68	96	57	76
7	75	67	71	97	57	77	71	65	68	92	59	76
8	75	67	71	87	53	70	67	64	66	80	58	69
9	75	66	71	88	48	68	69	62	66	89	53	71
10	76	66	71	95	50	73	69	62	66	89	51	70
11	77	67	72	95	54	75	69	62	65	87	54	71
12	74	66	70		48	66	68	61	65		44	69
13	73	64	68	85	46	66	64	61	63	75	46	60
14	74	64	69	90	46	68	61	60	60	68	54	61
15	74	65	69	90	49	70	60	56	58	68	43	55
16	74	65	69	89	51	70	62	57	59	72	50	61
17	74	65	70	92	50	71	62	56	59	72	38	54
18	76	66	71	98	53	75	62	57	59	74	41	57
19	75	67	71	94	56	75	63	57	60	83	43	57
20	74	66	70	89	53	71	63	59	61	74	52	63
21	74	64	69	86	51	69	60	57	59	66	43	54
22	74	65	69	92	53	72	60	55	58	66	33	49
23	73	65	69	98	53	75	61	56	58	70	43	57
24	72	64	68	85	52	68	60	55	57	70	36	53
25	70	63	66	80	47	63	61	54	57	73	34	53
26	71	62	66	84	43	63	60	54	57	79	44	61
27	71	62	66	85	43	64	58	57	57	62	56	59
28	71	63	67	84	43	64	70	55	57	68	43	55
29	71	62	67		47	68	59	54	57		35	51
30	73	63	68	89	46	67	60	54	57	70	36	53
31	72	74	68	94	45	69						

TABLE XXIV

STATION NO. 3

Richland
Water and Air Temperatures in Degrees of Fahrenheit

	August						September					
	Water Temp.			Air Temp.			Water Temp.			Air Temp.		
Date	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
1	75	69	72	95	67	81	74	66	70	98	53	76
2	74	68	71	91	54	73	74	68	71	99	55	77
3	74	66	70	87	52	70	75	69	72	101	61	81
4	75	67	71	88	54	71	73	68	71	101	65	83
5	76	68	72	94	56	75	74	68	71	99	60	80
6	78	69	74	100	61	81	72	69	71	101	62	82
7	77	70	74	104	64	84	72	68	70	101	64	83
8	77	69	73	100	59	80	70	65	68	96	60	78
9	76	69	73	91	57	74	71	66	69	84	55	70
10	77	69	73	94	60	77	70	66	68	91	54	73
11	77	70	74	100	62	81	69	64	67	95	56	76
12	77	70	74	101	55	78	66	65	66	90	48	69
13	75	68	72	90	57	74	65	61	63	83	50	67
14	74	68	71	90	54	72	60	58	59		56	67
15	74	69	72		57	76	63	59	61	78	50	64
16	74	68	71	95	58	77	63	59	61	69	51	60
17	75	67	71	92	56	74	64	59	62	73	44	59
18	76	69	73	96	60	78	64	60	62	74	48	61
19	76	70	73	99	67	83	64	60	62	79	46	63
20	76	70	73	95	59	77	63	61	63	85	56	71
21	75	68	72	88	55	72	61	57	59	75	48	62
22	74	68	71	92	56	74	62	58	60	71	37	54
23	73	67	70	94	55	75	61	58	60	73	48	61
24	73	67	70	91	54	73	62	57	60	76	40	58
25	72	65	69	87	55	71	61	57	59	75	40	58
26	71	65	68	81	49	65	60	59	60	76	45	61
27	72	66	69	89	51	70	60	58	59	81	57	69
28	71	66	69	92	61	77	60	57	59	68	48	58
29	72	66	69	89	54	73	61	57	59	68	42	55
30	73	66	70	98	57	78				69	40	55
31	73	67	70	102	57	80						

APPENDIX C

97.A

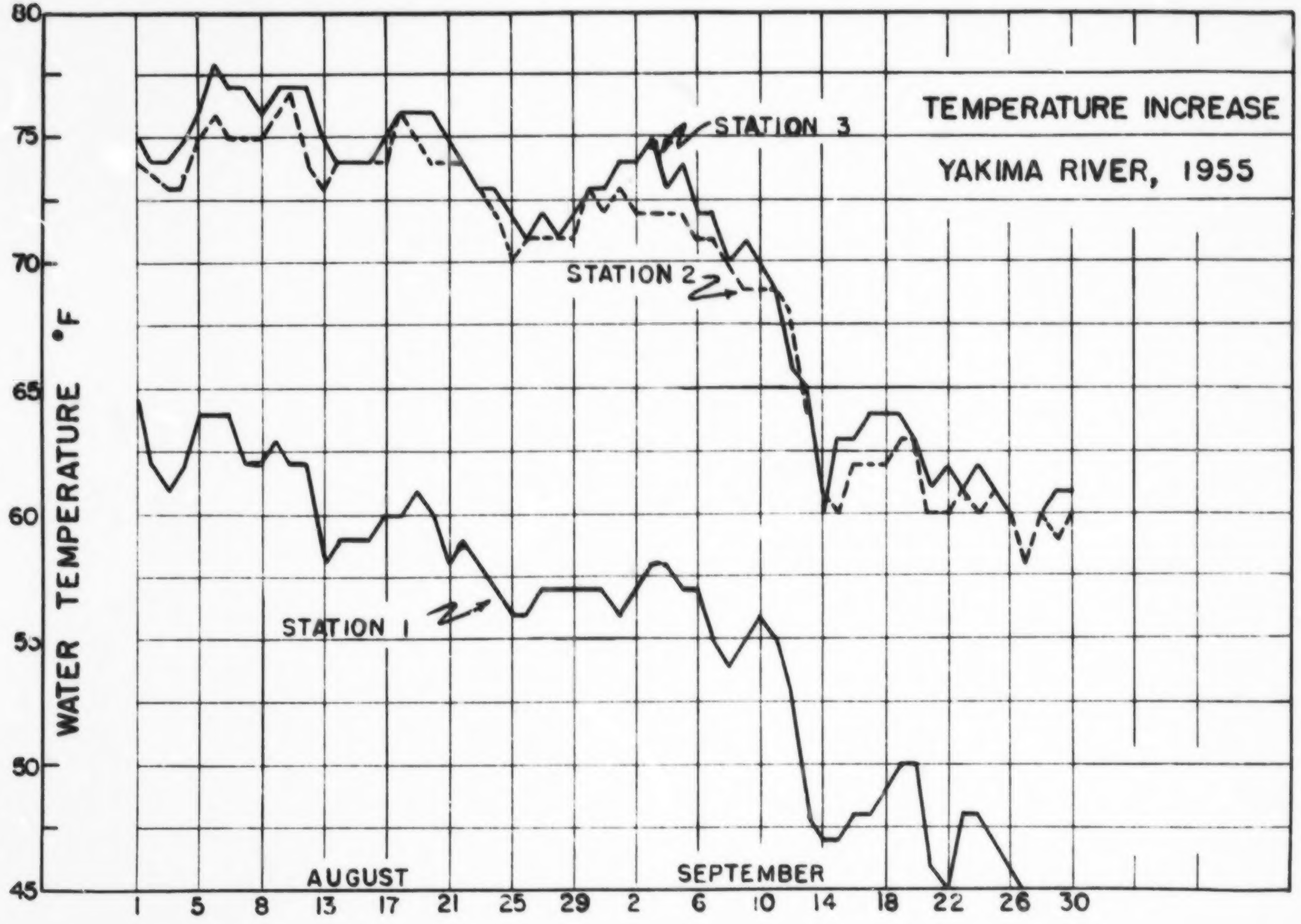

TEMPERATURE INCREASE
YAKIMA RIVER, 1955
STATION 3
STATION 2
STATION 1
WATER TEMPERATURE °F
80
75
70
65
60
55
50
45
1
5
8
13
17
21
25
29
2
6
10
14
18
22
26
30
AUGUST
SEPTEMBER

FIGURE 17

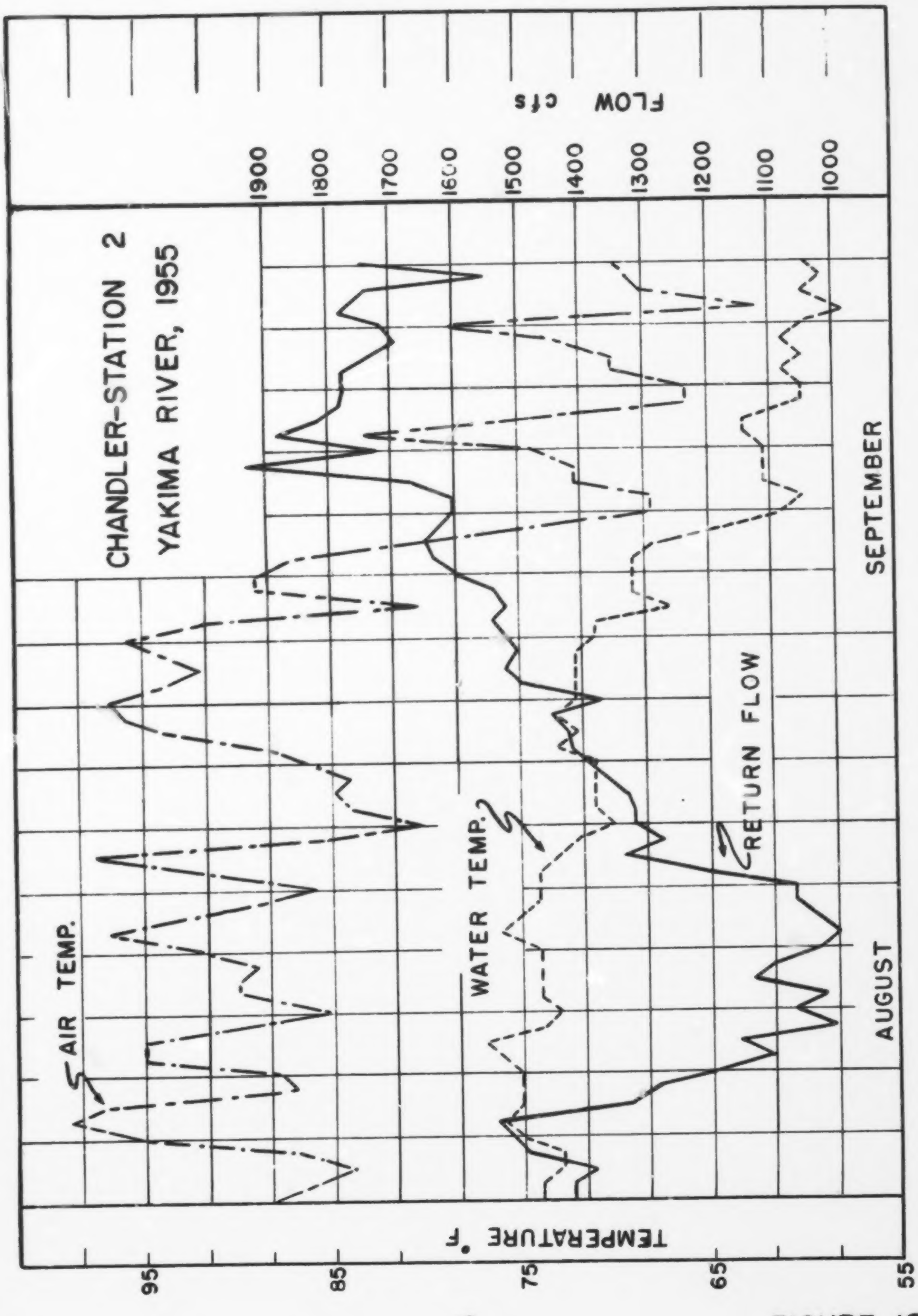

CHANDLER-STATION 2
YAKIMA RIVER, 1955
AIR TEMP.
WATER TEMP.
RETURN FLOW
AUGUST
SEPTEMBER
TEMPERATURE °F
95
85
75
65
55
FLOW cfs
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000

FIGURE 18

APPENDIX C

WATER QUALITY REQUIREMENTS

Water quality requirements are governed by the use to be made of the water. The major uses which may be affected by the quality of return irrigation flows are: Community and rural domestic supply, industrial supply, irrigation, stock and wildlife watering, fish and aquatic life propagation, boiler water supply, recreation, including boating and sports fishing, commercial fishing, and sewage and industrial waste effluent disposal.

The quality of irrigation supply, since it directly affects the quality of irrigation return water, has been discussed in detail in the main body of this report. Water quality requirements or criteria for other uses will be presented here. This information is essential to an interpretation of the effects of return irrigation flows on these uses.

Domestic Supply, Sanitary

Water used for drinking and other domestic purposes should meet sanitary quality provided for by the U. S. Public Health Service Drinking Water Standards (80) (81). These standards provide for two conditions, namely, the quality at the source, if treatment is required and provided; and the quality of the water delivered to the consumer. These two conditions merge into one in the case of rural and many community supplies. The sanitary quality of water delivered to the consumer is well established and is controlled by public Health agencies; therefore, it will not be discussed in detail here. Of more significance to the return water study is the need for treatment and the conditions governing this need. The Public Health Service Manual of Recommended Water-Sanitation Practice (81) classifies water into four groups as regards the treatment requirements on the basis of sanitary requirements. These are:

"Group 1, Water Requiring No Treatment. This group is limited to underground waters not subject to any possibility of contamination, and meeting in all respects, the requirements of the PHS Drinking Water Standards."

"Group 2. Waters Requiring Simple Chlorination, or Its Equivalent. This group includes both underground and surface waters subject to a low degree of contamination, and meeting the requirements of the PHS Drinking Water Standards in all respects except as to coliform bacterial content, which should not average more than 50 per 100 ml in any month."

"Group 3. Water Requiring Complete Rapid-Sand Filtration Treatment of Its Equivalent, Together with Continuous Postchlorination.

This group includes all waters----containing numbers of coliform bacteria averaging not more than 5000 per 100 ml in any one month and exceeding this number in more than 20 per cent of all samples examined in any one month."

"Group 4. Waters Requiring Auxiliary Treatment in Addition to Complete Filtration and Postchlorination. This group includes waters meeting the requirements of Group 3 with respect to the limiting monthly average coliform numbers, but showing numbers exceeding 5000 per 100 ml in more than 20 per cent of the samples examined and not exceeding 20,000 per ml in more than 5 per cent of the samples examined in any one month."

Domestic Supply, Physical and Chemical

Table 25 gives the limiting physical and chemical quality characteristics recommended for waters for domestic use.

Hardness is one of the most significant water quality characteristics affected by return irrigation flows. Waters are usually classified in relation to hardness as follows: (In terms of ppm as $CaCO_3$).

Class 1 - Soft	-0 to 55 ppm
Class 2 - Slightly hard	-56 to 100 "
Class 3 - Moderately hard	-100 to 200 "
Class 4 - Veryhard	-200 to 500 "

Among the objectionable features of a hard water when used for domestic purposes are scalling in water heating equipment, the cost of soap, scum, and effect on clothes during washing. These problems largely involve economic considerations.

Water having a hardness less than 75 ppm is generally considered satisfactory for domestic use. Hardness from 75 to 150 ppm does not usually interfere seriously with its use for most domestic purposes or cause a demand for water softening. Hardness above 150 ppm is marginal and if above 200 ppm many homes will provide water softening devices or a public demand may require community softening facilities. This is not to say that waters in excess of 200 ppm hardness are not used for domestic supplies. Hard water is used in many cases, however, its use is expensive and attended with difficulties.

Boiler Waters

The requirements for a good boiler water are - entire freedom from turbidity and non-carbonate (permanent hardness) and a total hardness not to exceed 35 ppm. All hardness must be removed if the water is used in high pressure boilers. Corrosion is caused by mineral acids and salts. Magnesium chloride is especially objectionalable since it breaks down in the boiler to form hydrochloric acid. Excessive concentrations of salts

TABLE XXV

LIMITING PHYSICAL AND CHEMICAL CHARACTERISTICS FOR DOMESTIC WATER

Physical	
Turbidity	Not greater than 10 ppm
Color	Not greater than 20 ppm
Taste and odor	Not objectionable
Chemical	
Dissolved solids	Not greater than 500 ppm
Fluoride	" " " 1.5 ppm
Arsenic	" " " 0.05 ppm
Iron and manganese	" " " 0.3 ppm
Magnesium	" " " 125 ppm
Chloride	" " " 250 ppm
Sulfate	" " " 250 ppm
Nitrate as N	" " " 10 ppm
CO_3, normal	" " " 120 ppm
pH	" " " 10.6 ppm

cause foaming. Sulfates and chlorides of sodium cause imbrittlement and reduce the life of boiler tubes and surfaces. Table 26 shows some of the quality requirements for boilers of various pressures (86).

Industrial Supply

The quality of water for industrial uses is often more exacting than for domestic supply. Because of the wide variation in industrial processes, there is an equally wide variation in the desirable quality of water.

The sanitary requirements for water for most food industries is the same as that for domestic use. Other characteristics can only be considered in a very general way. Table 27 was prepared from several reports (74) (78) (82) (83) (84) (85) (86) and indicates the range of quality desired in an industrial water.

Fish and Aquatic Life

Information regarding the water quality requirements for fish and aquatic life is scarce and much of it is not dependable. So many factors influence the effects of water constituents on aquatic life that a concise statement regarding a specific requirement is not possible.

For instance, adverse water quality may affect fish in many ways. It may interfere with migration, destroy them due to toxicity, provide a favorable media for disease, interfere with spawning, destroy eggs and young fish, and prevent the production of an adequate food supply. Fish in various stages of growth may react differently to water quality (26) (27) (28) (88) and the species may have different requirements. Constituents react differently under varying temperature and hardness or alkalinity conditions or they may be synergistic or antagonistic.

Because of these variations, the actual effect of a specific water on aquatic life can only be determined by bioassay. However, there are some general conditions which can be applied.

Temperature is one of the more critical factors affecting fish life. Here again the type of fish and the location governs the tolerance to temperature. Tarzwell (29) reports as follows: Peak temperatures in the northern states should not exceed 93°F for warm water fish or 80°F for trout. In the South temperatures up to 96°F can be tolerated by resident fish. For best production summer temperatures for game fish should range from 60 to 68°F.

According to Frazer River studies (87) salmon (sockeye) react more to increased temperature as they approach their spawning grounds. Large numbers will not spawn if the temperature exceeds 63°F. Prior to

TABLE XXVI

SOME WATER QUALITY REQUIREMENTS FOR BOILER WATER

Pressure-------------lbs. per sq. in.	0-150	150-200	250-400	Over
Total solids	3000-500	2500-500	1500-100	50
Turbidity	20	10	5	1
Total hardness	80	40	10	2
Bicarbonate	50	30	5	0
Carbonate	200	100	40	20
Sulfate-Carbonate ratio*	1:1	2:1	3:1	3:1
Silica	40	20	5	1
pH	8.0	8.4	9.0	9.6

*($Na_2SO_4 : Na_2CO_3$)

TABLE XXVII

WATER QUALITY REQUIREMENTS FOR INDUSTRIAL USES

	Total Solids	Turbidity	Color	Hardness	Alkalinity	
Use	ppm	ppm	ppm	ppm	ppm	pH
Baking		10	10			
Brewing, light	500	10			75	6.5-7.0
Brewing, dark	1000	10			150	7.0
Carbonated beverage	850	2	10	250	50	
Canning		10		75		
Confectionary	100					7.0
Ice	300	5	5		50	
Laundering				50		
Plastic	200					
Pulp and paper						
Groundwood		50	20	180		
Kraft pulp	300	25	15	100		
Sulfite	200	15	10	100		
Paper	200	5	5	50		
Tanning		20	10	50	135	8.0
Rayon, pulp	100	5	5	8	50	
Rayon, production		0.3		55		7.8-8.3

reaching the spawning areas they will tolerate temperatures up to 70°F. At and above 70°F, however, columnaris disease may wipe out large populations of the salmon. These studies indicate that these salmon will die when the mean water temperatures exceed 68°F for a period of several days.

Other pertinent requirements for maximum fish production are:

Hydrogen ion concentration - 6.7 to 8.6.

Dissolved oxygen above 5.0 ppm.

Specific conductance at 25°C 150 to 500 mho^{x} 10^{-6} (1000 to 2000 mho x 10^{-6} permissible in western alkaline areas).

Dissolved solids up to 3000 ppm if not toxic and are physiologically balanced.

Suspended solids (turbidity) such that the millionth intensity level for light penetrations will not be less than 5 meters.

Carbon dioxide, not over 30 ppm.

Ammonia, not over 1.5 ppm

DDT - concentrations less than 0.1 ppm may be lethal.

Fluorides - not over 100 ppm

Nitrates and phosphates - not toxic

Calcium, magnesium, sodium sulfates and chlorides are apparently not toxic in normal concentrations.

APPENDIX D

APPENDIX D

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CONVERSION TABLE

1 Acre---= 43,560 square feet

1 Cubic foot---= 7.5 gallons

1 Acre foot--= 325,851 gallons

1 Million gallons------------------------------------= 3.07 acre-feet

1 Acre foot per day----------------------------------= 2 cubic feet second (approx)

Milliquivalents per liter (Meq/l) to parts per million (ppm)

Multiply meq/l by equivalent weight

Parts per million (ppm) to milliequivalents per liter (Meq/l)

Divide ppm by equivalent weight

Equivalent weights

Calcium ion--------------------------------= 20.04
Magnesium ion------------------------------= 12.06
Sodium ion---------------------------------= 23.00
Bicarbonate ion----------------------------= 61.01
Sulfate ion--------------------------------= 48.03
Chloride ion-------------------------------= 35.46
Nitrate ion--------------------------------= 62.01